STUDIES ON FLUIDIZATION CHARACTERSTICS OF FINE PARTICLES IN A GAS-SOLID FLUIDIZED BED

A Project submitted to the

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In partial fulfillment of the requirements

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By

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CERTIFICATE

This is to certify that the thesis entitled **STUDIES ON FLUIDIZATION CHARACTERSTICS OF FINE PARTICLES IN A GAS-SOLID FLUIDIZED BED** , submitted by **Debashis Biswal** to National Institute of Technology, Rourkela is a record of bonafide project work under my supervision and is worthy for the partial fulfillment of the degree of Bachelor of Technology (Chemical Engineering) of the Institute. The candidate has fulfilled all prescribed requirements and the thesis, which is based on candidate's own work, has not been submitted elsewhere.

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Abstract

Attempt has been made to study the fluidization characteristics of fine particles in a gas-solid system. Experiments on the fluidization of fine-particles of different sizes and densities were carried were carried out in a cylindrical column of 5cm dia. Fluidization characteristics such as bed expansion, bed fluctuation, bed pressure drop in turn the Euler Number of fine particles have been tried to be analysed by varying the different system parameters. In the present work, attempt has been made to fluidize fine particles by changing the surface property of the particles using a stirrer. These fluidization characteristics have been correlated against the different system parameters (viz. static bed height, particle size, particle density, speed of the stirrer and superficial velocity of the medium) on the basis of Dimensionless Analysis approach. Finally calculated values of different fluidization characteristics have been compared against the experimentally observed values. The result show a good agreement among the experimental and calculated values thereby indicating the application of these developed correlations over a wide range of parameters.

Key-Words: Bed expansion and Bed-Fluctuation Ratio, Euler's No., Fluidized bed with the stirrer

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NOMENCLATURE

$d_{p:}$ Particle diameter

Dc: Column diameter

ΔP : Pressure difference

U_O: Superficial velocity

Umf: Minimum fluidization velocity

Uavg: (Uo-Umf)

Hs: Static bed height

N: Speed of stirrer

ρ_s : Density of solid

ρ_f : Density of fluid

$€_{mf}$ = Voidage ;

μ_f = Viscosity of fluid;

Φ_s= Sphericity ;

SUBSCRIPTS

avg- average

del- Delta

E.N- Euler's No

mf- minimum fluidization

sup- superficial

CHAPTER 1

INTRODUCTION

Gas-solid fluidiziations have found more industrial applications due to good solid-fluid mixing. The important advantages of the gas-solid fluidized beds are smooth, liquid-like flow of solid particles. This permits a continuous automatically-controlled operation with ease of handling and rapid mixing of solids which leads to a near isothermal condition throughout the bed. This results in a simple and controlled operation with rapid heat and mass transfer rates between gas and particles, thereby minimizing overheating in case of heat sensitive products. Some of the important applications of gas-solid fluidized beds are in the dairy, cement industries, food and pharmaceutical industries for drying, cooling, coating and agglomeration.

Formation of large scale bubbles during the fluidization reduces the heat and mass transfer rate which affect the output of the system. Hence persistent effort have been made by the investigators to improve the quality of gas-solid fluidization by promoting bubble breakage and hindering the coalescence of bubbles which result in reduced bed expansion and fluctuation and better gas-solid mixing .This is the main disadvantage when the fluidized bed are used in chemical and petrochemical industry where it fluidization is accompanying with chemical reaction. Reducing in gas-solid mixing reduces the rate of chemical reaction.

Fluidization quality is closely related to particle intrinsic properties such as particle size, particle density ,size distribution of particle and its surface characteristics. As the particle size decreases the cohesive force (i.e. Vander Wall Force) for the particle increases. So due to this effect the method of fluidization for fine particle becomes much more difficult as compared to the larger size particle. It was also pointed out by Geldart in his classification map, fine particle in Group C (small particle size and low particle density) fluidize poorly due to their strong inter-particle cohesive forces, exhibiting channeling, lifting as a plug and forming ‘‘rat holes’’ when aerated. Therefore, the development of reliable techniques to improve the fluidization of cohesive fine powders is required. Several external devices based on using vibration and mechanical agitation have been suggested to improve the flow ability of cohesive fine particle. Despite the use of these devices, handling of fine particle is still extremely difficult and wet processing, such as coating and granulation of fine particle has been regarded as nearly impossible.

Preconditioning methods have been developed that help to decrease cohesion, which results in non-bubbling fluid-like fluidization of fine powders. For example, xerographic toners (powders of micron sized particles), with cohesion reduced by surface coating, have been shown to transit from the solid-like regime to uniform non-bubbling fluidization as the gas flow is increased. Experimental results have shown that it was possible to improve fluidization uniformity of Ni/SiO_2 aerogels by decreasing the strength of inter-particle forces, which could be influenced by initial bed compaction, gas moisture content and admixture of inert particles and the oxidized state of Ni .

The type of fluidizing gas also significantly affects the fluidization quality of fine particles. It has been found that the fluidization behaviour of Geldart group A particles is strongly dependent on the type of fluidizing gas. In the work of Geldart and Abrahamsen (1978), it has been demonstrated that the bubbling and bed expansion behaviours of group A particles of alumina and glass beads greatly differ with the type and pressure of the fluidizing gas. It has been observed that a group A powder may behave more "A-like" when using different types of fluidizing gas. According to Piepers et al. (1984), physically adsorbed gases may enhance the cohesion of particles, resulting in an increased elastic modulus of a fluidized bed and a growth in the bed expansion.

In the present experimental work fluidization of fine particle had been carried out in a 2-dimensional fluidized bed with the help of a stirrer. With the application of stirrer in the fluidized bed ,the general problem of fluidizing fine particle such as channeling, slugging etc. had been counter reacted. Different size fine particle of different material are used for the experiments. There variation with various parameter such as particle size (dp), bed height (Hs), superficial velocity (Uo) and rotational speed of stirrer (N) had been studied. The correlations for (1) expansion ratio '***R***',(2) fluctuation ratio '***r***' and (3) Euler number with the above mentioned parameter have been developed.

CHAPTER 2

LITERATURE REVIEW

Fluidization is an established fluid-solid contacting technique. A fluidized bed can be achieved by increasing the upward velocity of the fluid through a fixed bed of solid particles. Fluidized bed technique as compared to fixed bed has the unique advantage of a smooth, liquidlike flow of solid particles which allows continuous and automatically-controlled operation with ease of handling and rapid mixing of solids. In spite of these advantage, the applications of gas-solid fluidized bed have been constrained due to certain inherent drawbacks like channelling, uncontrolled bed expansion and fluctuation because of formation of bubbles and their subsequent collapsing, and slugging. These not only reduce the heat and mass transfer rate thereby affecting the outcome of the system, but influence the fluidization quality to a considerable extent. When the particle size reduces these problems predominant in the fluidization process . A brief survey on these problem had been made in the following :-

2.1 Bubbling: A gas-solid fluidized bed is characterized by the presence of gas voids or bubbles causing a resistance to mass and heat transfer. Bubbles in gas fluidized bed are very important as they are responsible for most of the features that differentiate a packed bed from a fluidized one. The quality of fluidization specially in terms of expansion and fluctuation depends largely on the formation of bubbles and their growth in the direction of flow. Modification of gas flow promotes the formation of bubbles of smaller size through the system and cause particle movement which generally results reduced expansion and fluctuation, rapid and extensive particle mixing and a consequent high heat transfer co-efficient.

2.2 Slugging: The gas-solid fluidization is characterized by the formation of bubble. The size of the bubble increases and sometimes even its diameter may become equal to that of the column. When the bubble diameter approaches the column diameter, it is termed as slugging. An aggregatively fluidized bed in a column of small diameter operated at sufficiently high gas velocity will show continuous slug flow. Slugging affects adversely the fluidization quality. Once slugging occurs, the portion of the bed above the bubble is pushed upwards, as by a piston. Particle rain down from the slug and the slug finally disintegrates. Periodically another slug forms and thus unstable oscillatory motion is repeated. Slugging increases the problem of entrainment and lowers the performance potential of the bed. Slugging is especially serious in long narrow fluidized beds.

2.3 Channeling: The quality of fluidization specially in term of mixing is greatly affected by channeling. As the flow rate through a bed of particle increases towards minimum fluidization of the bed materials, channeling may occur. The non-uniformity in size of bed materials and poor mixing between the fluid and the particles in the bed may lead to channeling. At the onset of the formation of channeling, the fluid tends to pass through the bed along such paths of lower particle concentration. Channeling can result from initial non-uniformity in the bed and tends to be accentuated by stickiness of the particle which prevents them from flowing into the channeled region. Where the fluid velocity is significant, the solid particles develop an upward movement, while in case of lower fluid velocity they go downwards. The local increase in velocity through the bed above minimum fluidization, causes the bed to locally expand, thereby altering the pressure drop through that portion of the bed. The change in local pressure drop through the distributor and the combined pressure drop of the bed and the distributor quantify the channeling. A channel tends to become established if the local pressure drop through the bed-distributor system decreases with increased fluid velocity.

Apart from these the parameter that are studied during a fluidization process are:

- Minimum Fluidization Velocity (Umf)
- Pressure Drop (Δp)
- Bed Expansion Ratio (R)
- Bed Fluctuation Ratio (r)

2.4 Minimum Fluidization Velocity: When a fluid passes upwards through the interstices of a bed of solids without the slightest disturbance of the solids, the bed is called a fixed bed. With further increase in the velocity of fluid, the entire bed of solids is suspended and behaves as if its weight is counterbalanced by the force of buoyancy. At this point, the bed of solids starts behaving like a fluid. This is called onset of fluidization and the velocity of fluid at which it happens is called minimum fluidization velocity, which is one of the most important parameter for the design of fluidizers.

There are several correlations on minimum fluidization velocity proposed by Leva [57] , Rowe and Henwood[58], Narsimhan [59], Wen and Yu [60], Richardson [61] etc.. Out of which Ergun's correlation [62] being used over a wide range of Reynolds number is given below:

$$\frac{\Delta p_b}{h_s} = 150\frac{\left(1-\varepsilon_{mf}\right)^2 \mu_f U_{mf}}{\varepsilon_{mf}^3 \left(\phi_s d_p\right)^2} + 1.75\frac{\left(1-\varepsilon_{mf}\right)\rho_f U_{mf}^2}{\varepsilon_{mf}^3 \phi_s d_p} \tag{1}$$

Where :

Δp_b = Pressure drop across bed ;

h_s = Static bed height ;

$€_{mf}$ = Voidage ;

μ_f = Viscosity of fluid;

Umf= Minimum fluidization velocity;

ρ_f = Density of fluid;

Φ_s= Sphericity ;

2.5 Pressure Drop: The pressure drop through the bed is another important parameter which controls the channel and slug formation and thereby mixing of the bed material with the fluidizing fluid. At low flow rates in the packed bed, the pressure drop is approximately proportional to gas velocity upto the minimum fluidization condition. With a further increase in gas velocity, the packed bed suddenly unlocks (at the onset of minimum fluidization condition), resulting in a decrease in pressure drop. With gas velocities beyond minimum fluidization, the bed expands and gas bubbles are seen to rise resulting in nonhomogeneity in the bed. With the increase in gas flow, the pressure drop should remain unchanged but due to bubbling and slugging there is always a fluctuation in the pressure drop and it increases slightly . Particularly for coarse particles, the mean total pressure drop across a slugging bed may continue to increase with gas velocity higher than at the minimum fluidization condition. For fine particles the variation of pressure drop with gas velocity is quasi-linear when they are fluidized by classical method of fluidization as they form cranks and channel. Particulate fluidization generally gives rise to a homogeneous fluidization. However, this ideal situation is not realized in practice and significant deviations have been observed.

2.6 Bed Expansion Ratio (R) : Expansion of gas-solid fluidized beds may in general result from the volume occupied by bubbles and from increase in voidage of the dense phase. Bed Expansion Ratio (R) is defined as the ratio of average height of bed (Havg) i.e (Hmax+Hmin)/2 and Static bed height Hs. Bed expansion ratio increases with increasing value of excess velocity and for distributors which give smaller bubbles. Very poor distributors which lead to channeling condition rather than bubbling reduce bed expansion ratio. Many Empirical relation for 'R' had been developed earlier using different experimental data.

2.7 Bed Fluctuation Ratio (r) : For gas flow more than the minimum fluidization velocity, the top of the fluidized bed may fluctuate considerably. The extent of the fluctuation and its estimation becomes important while specifying the height of a fluidizer. The fluctuation ratio 'r' is the ratio of the highest and the lowest level of the top of the bed for any fluidizing gas velocity. Consistent effort had been made to correlate fluctuation ratio in terms of static and dynamic parameters of the system as the bed fluctuation and fluidization quality are being inter related.

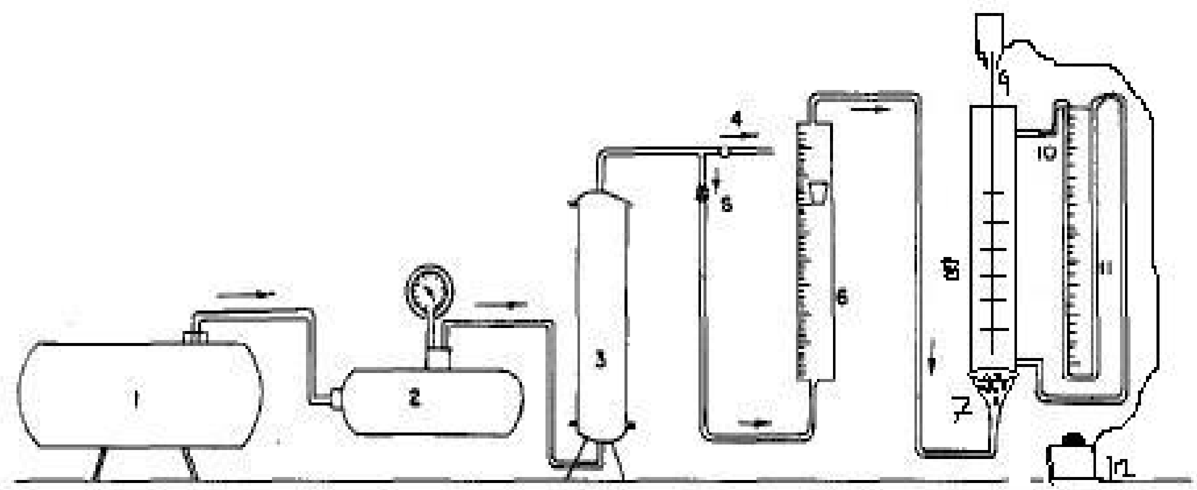
2.8 Euler Number ($\Delta p/Uo^2\rho_f$) : The Euler Number is a dimensionless value commonly

used for analyzing fluid flow dynamics problems where the pressure difference between two point is an important variable. The Euler Number can be interpreted as a measure of the ratio of pressure forces to inertial forces. Euler number is useful in analyising the pressure variation with other parameter of fluidization.

CHAPTER 3

EXPERIMENTAL SETUP

The experimental set-up consists of a fluidizer, rotameter, manometer, compressor, varriac-motor as shown in Fig-3.1 . The fluidization is carried out in side a cylindrical tube of dia. ‘5cm’.The distributor used for the process is packed bed type above which a filter cloth is placed. From the top of the bed a stirrer with a rod promoter is placed inside the tube to provide constant rotation. The rotameter used in the setup is of 0-10 lpm capacity. The tube is closed with filter cloth at the top to stop the entrainment of the particles. Two tubes one at top & another at bottom is connected to the manometer to measure the ΔP. Liquid used in the manometer is CCl_4. The distributor is packed with glass beads of uniform size so as to get uniform distribution of fluid to avoid channeling.



Apparatus in the set-up:

1:Compressor;**2:**receiver;**3:**Silicageltower, **4:**By pass valve; **5:**Line valve; **6:**rotameter;**7:**Packed bed distributor; **8:**fluidize bed;**9:**Stirrer with rod-promotor; **10:**mano meter; **12:**Variac;

Figure 3.1 : Schematic View of the Experimental Set-up

Figure 3.2 :Laboratory Set-up

3.1 Experimental Work :

- The fluidization is carried out with talcum powder (particle size d_p=65µm & d_p=80µm),alumina powder (particle size d_p=75µm),silicon carbide (particle size d_p=70µm) and magnetite ore (particle size d_p=60µm).
- With one fixed bed height the by varying the RPM of the stirrer four different experiment were done.
- Again with fixed rpm with different bed height experiment were carried out.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 OBSERVATION (Variation of Δp with superficial velocity (Uo))

4.1. 1 Material-Talcum Powder (dp=65 µm)

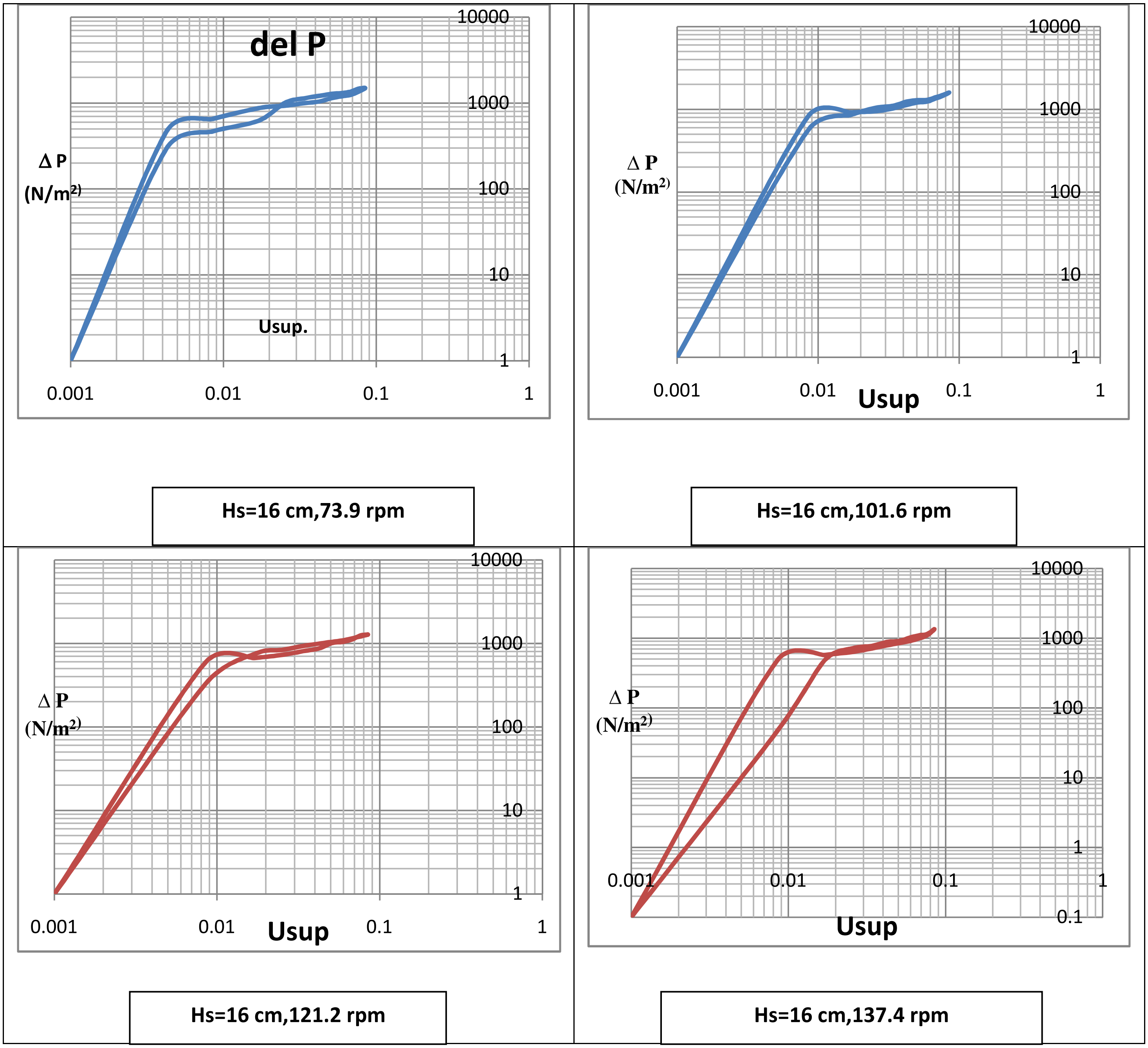


Figure 4.1.1 : With varying rpms of stirrer

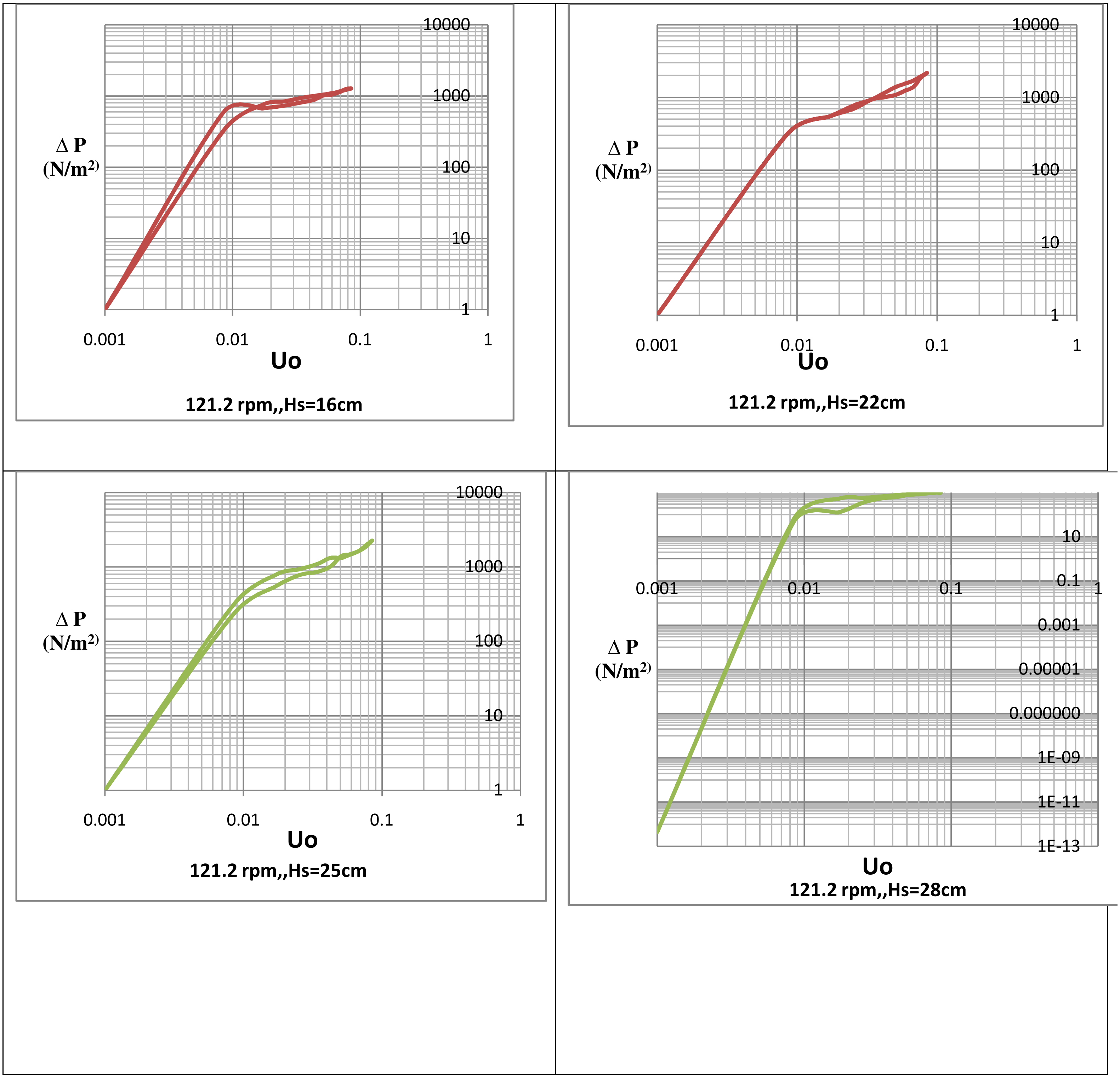


Figure 4.1.2 : With varying Static bed heights, Hs

4.1.2 Material-Talcum Powder(dp=80 µm)

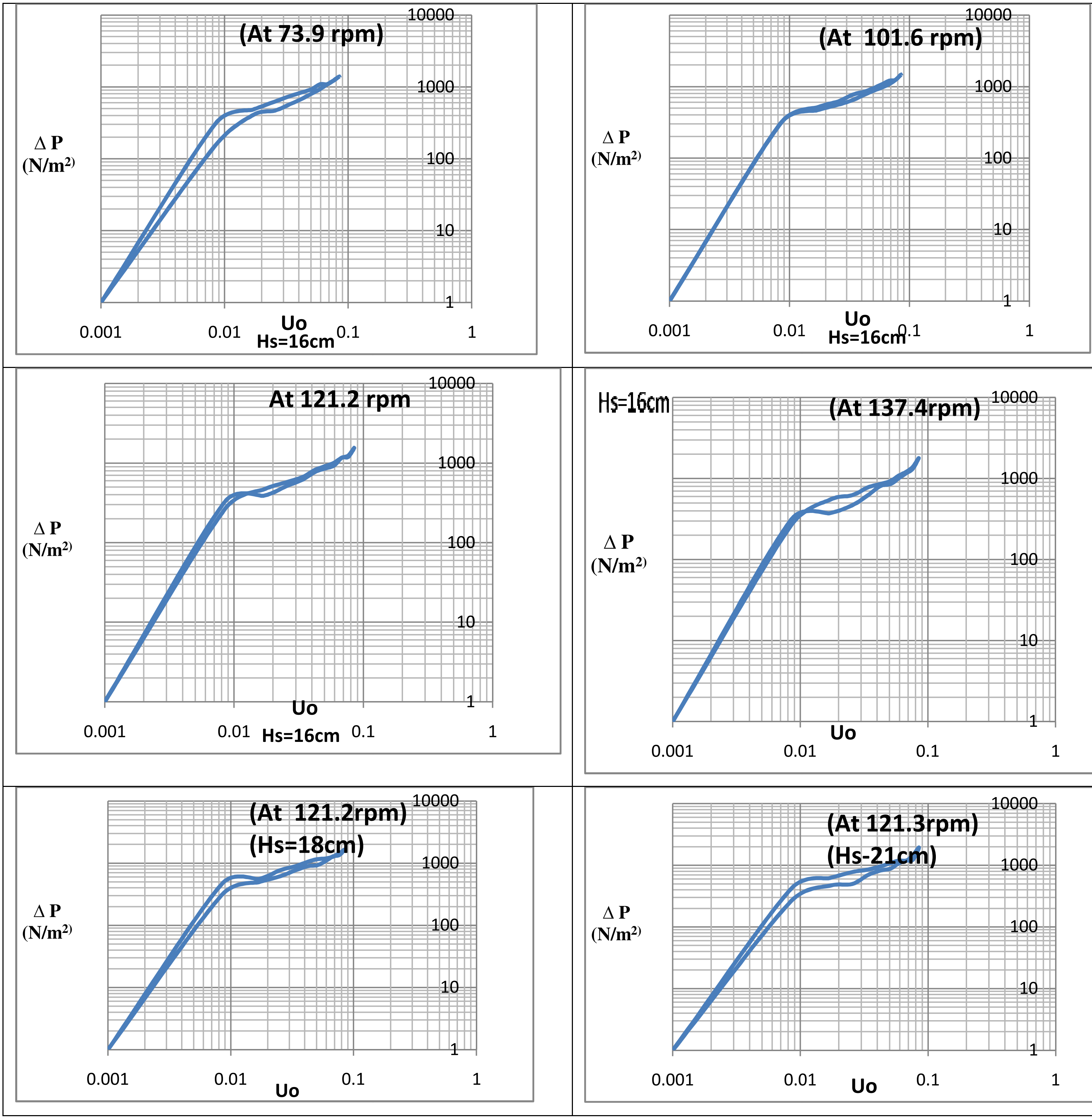


Figure 4.1.3 : With varying rpms of stirrer & Static bed heights, Hs

4.1.3 Material- Alumina Powder(dp=75 µm)

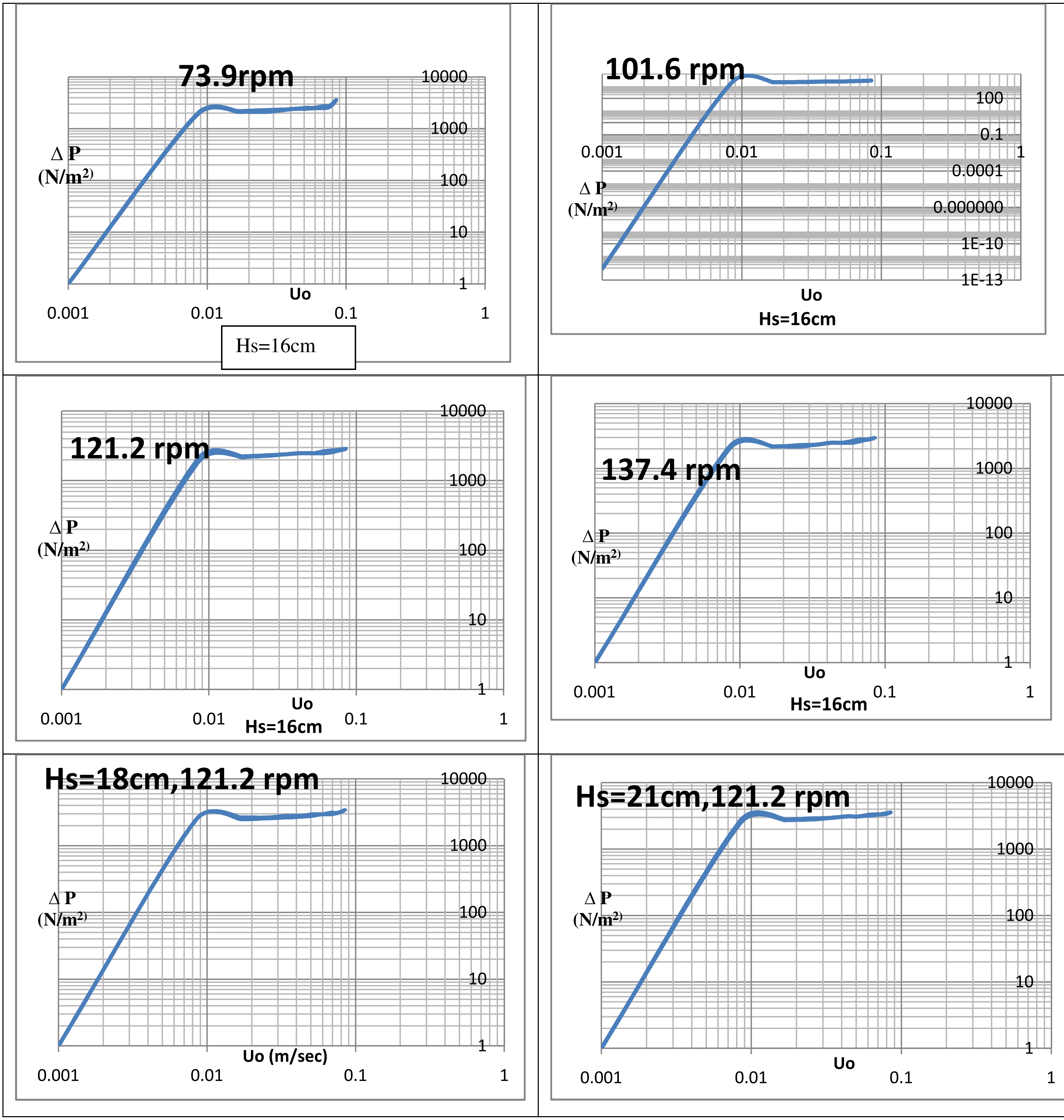


Figure 4.1.4 : With varying rpms of stirrer & Static bed heights, Hs

4.1.4 Material- Silicon Carbide(dp=70 μm)

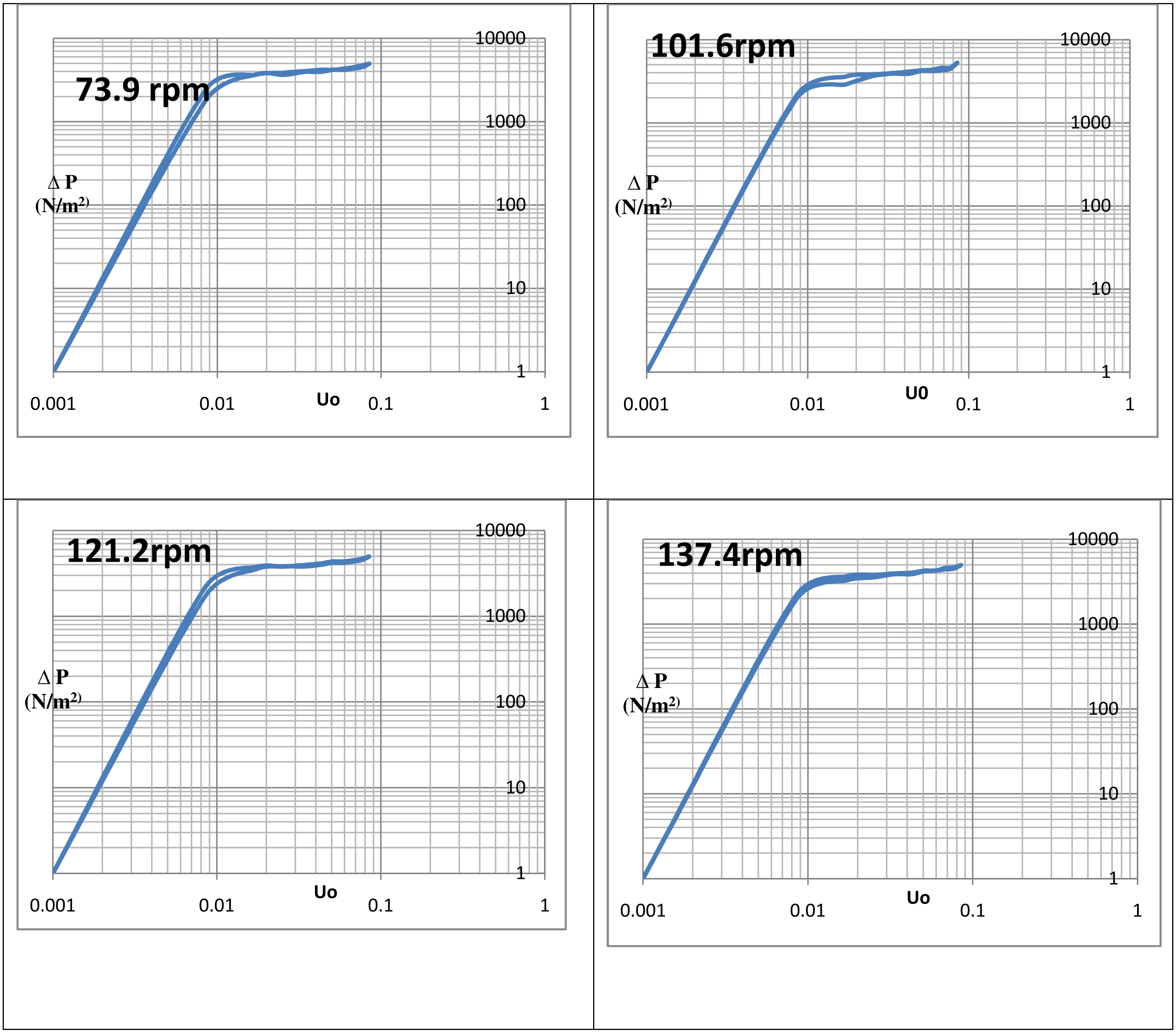


Figure 4.1.5 : With varying rpms of stirrer

4.1.5 Material- Magnetite(dp=60 µm)

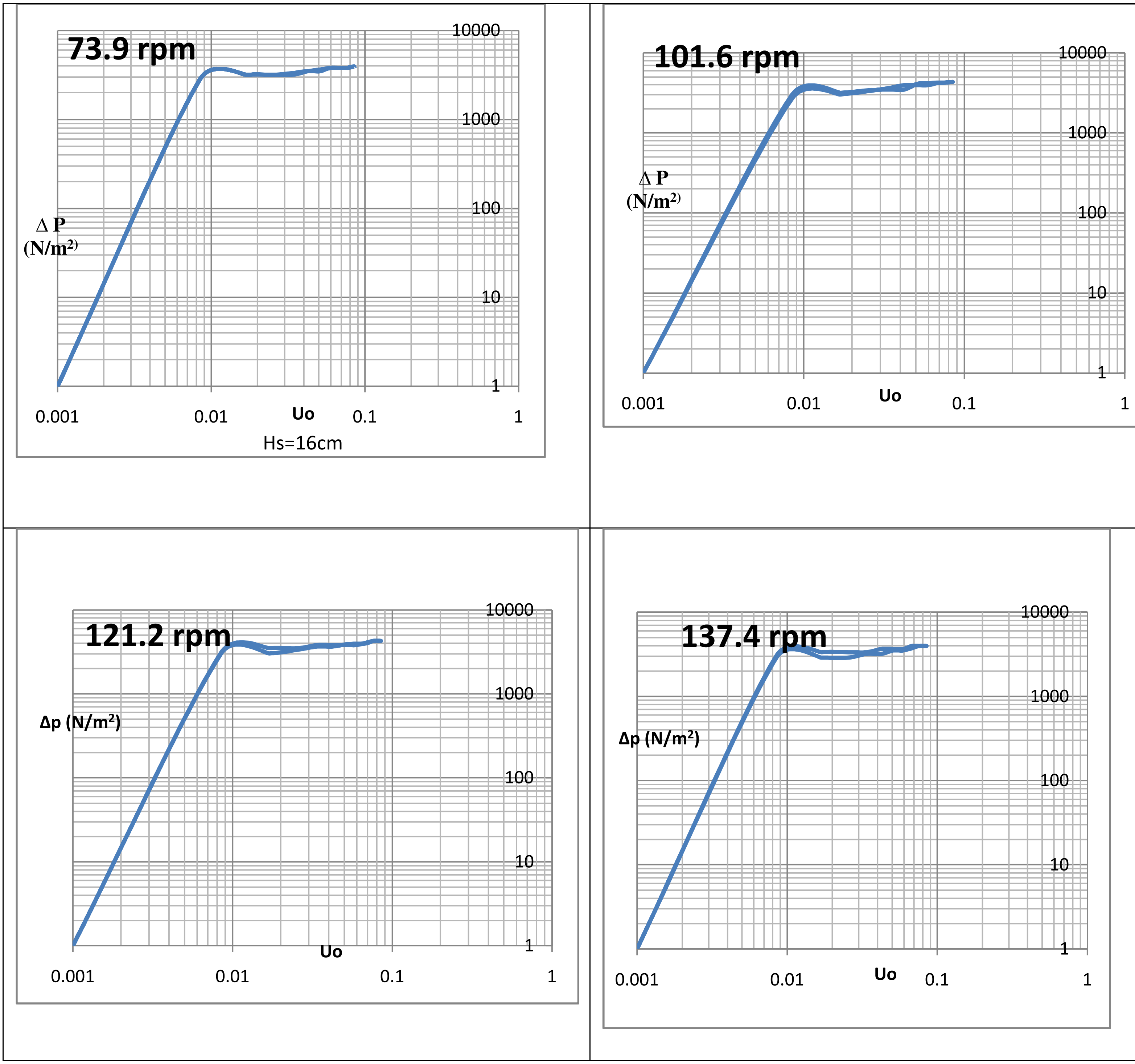


Figure 4.1.6 : With varying rpms of stirrer

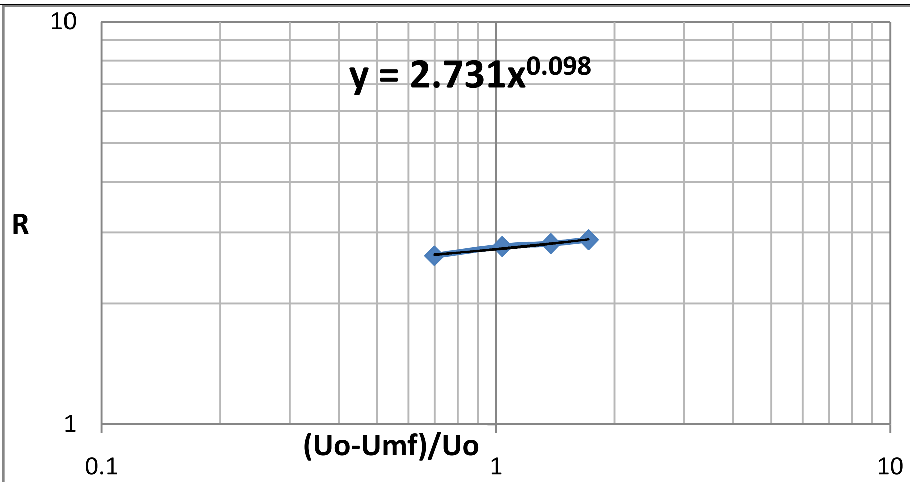
4.2 DEVELOPMENT OF CORRELATION

4.2.1 FOR BED EXPANSION RATIO (R)

Exponents Of Individual Parameters :

$(U_o$-Umf)/Umf	R
0.697793	2.625
1.037351	2.765
1.37691	2.8125
1.716469	2.875

R Vs (Uo-Umf)/Umf

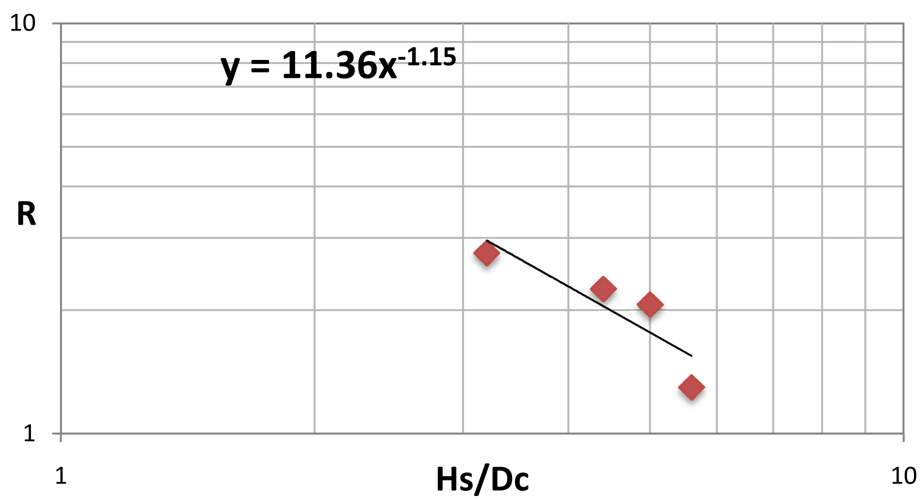


$R=2.731((Uo\text{-}Umf)/Umf))^{0.098}$

Figure- 4.2.1: R Vs (Uo-Umf)/Umf

Hs/Dc	R
3.2	2.75
4.4	2.25
5	2.06
5.6	1.294643

R Vs Hs/Dc

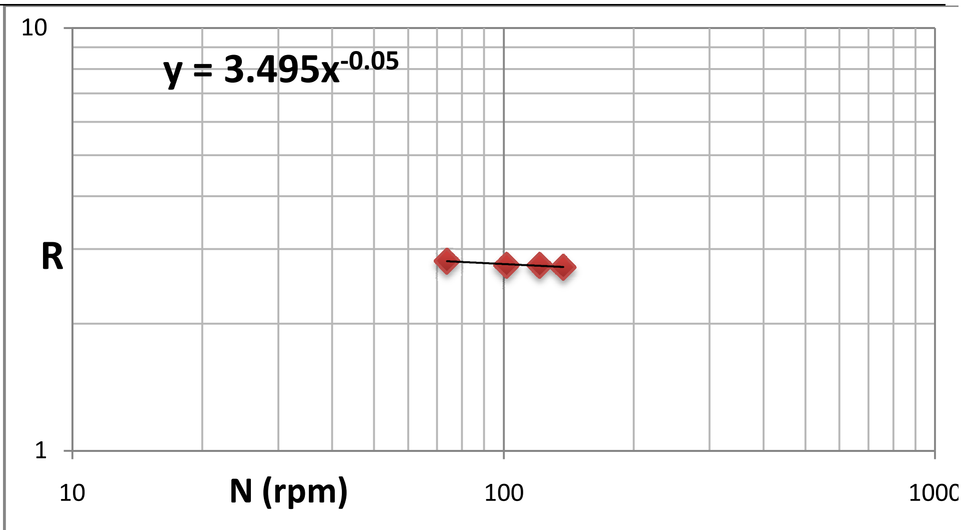


$R=11.36\ (Hs/Dc)^{-1.15}$

Figure 4.2.2 : R Vs Hs/Dc

N	R
73.9	2.8125
101.6	2.75
121.2	2.75
137.4	2.71875

R Vs N

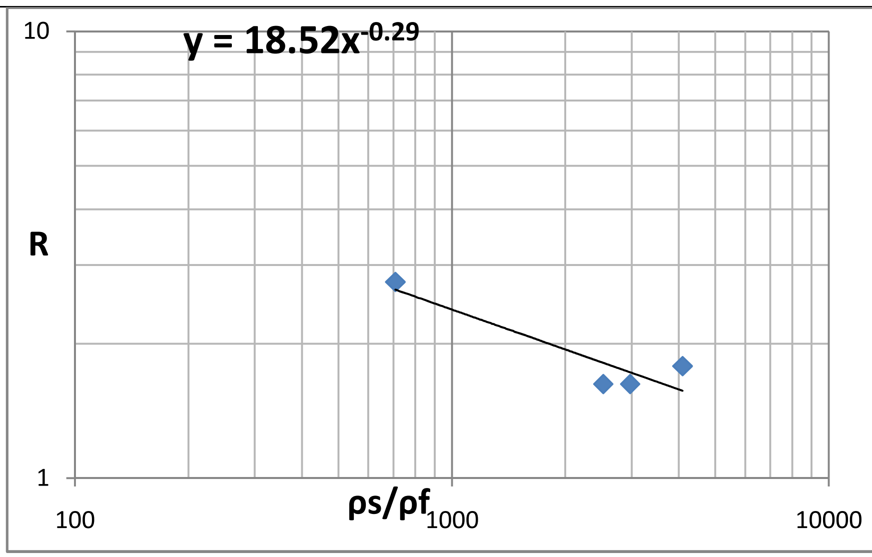


$$R = 3.495\, N^{-0.05}$$

Figure 4.2.3: R Vs N

ρ_s/ρ_f	R
708.6614	2.75
2968.504	1.625
2519.685	1.625
4094.488	1.78125

R Vs ρ_s/ρ_f

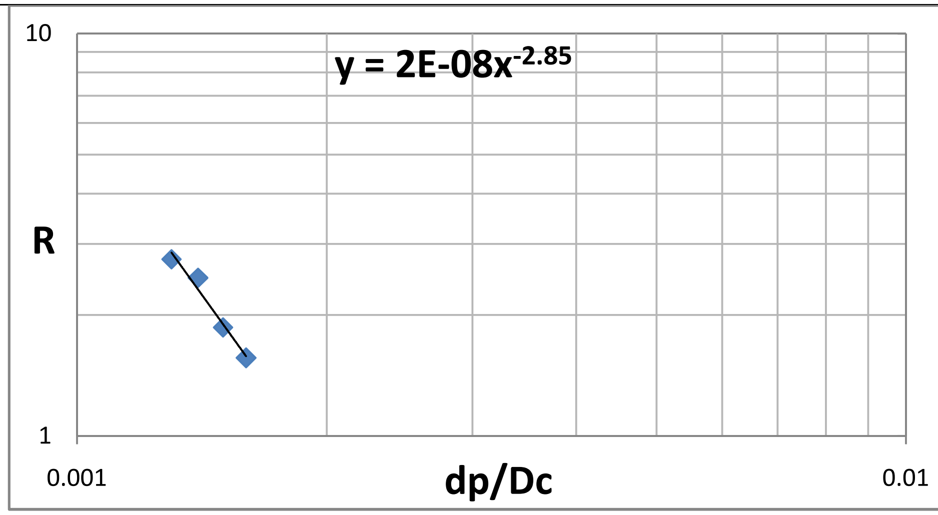


$$R = 18.52\, (\rho_s/\rho_f)^{-0.29}$$

Figure 4.2.4: R Vs ρ_s/ρ_f

dp/Dc	R
0.0013	2.75
0.0014	2.47149
0.0015	1.8601
0.0016	1.5625

R Vs dp/Dc



$R = 2E\text{-}08(dp/Dc)^{-2.85}$

Figure 4.2.5 : R Vs dp/Dc

Table 1 : Scope of the Experiment

S.l.No	Materials	Uo/Umf	Hs, cm	N, rpm	ρ_s, g/cc	dp in μm
1	Talcum Powder	1.25	16	73.9	0.9	65
2	Talcum Powder	1.5	16	73.9	0.9	65
3	Talcum Powder	1.75	16	73.9	0.9	65
4	Talcum Powder	2.0	16	73.9	0.9	65
5	Talcum Powder	1.75	16	121.2	0.9	65
6	Talcum Powder	1.75	22	121.2	0.9	65
7	Talcum Powder	1.75	25	121.2	0.9	65
8	Talcum Powder	1.75	28	121.2	0.9	65
9	Talcum Powder	1.75	16	73.9	0.9	65
10	Talcum Powder	1.75	16	101.6	0.9	65
11	Talcum Powder	1.75	16	121.2	0.9	65
12	Talcum Powder	1.75	16	137.4	0.9	65
13	Talcum Powder	1.75	16	121.2	0.9	65
14	Alumina	1.75	16	121.2	3.77	75
15	SiC	1.75	16	121.2	3.2	70
16	Magnetite	1.75	16	121.2	5.2	60
17	Talcum Powder	1.75	16	121.2	0.9	65
18	Talcum Powder	1.75	16	121.2	0.9	70
19	Talcum Powder	1.75	16	121.2	0.9	75
20	Talcum Powder	1.75	16	121.2	0.9	80

Table 2 –Observed Data & Comparison of Calculated Value of Expansion Ratio 'R' With Experimental 'R' Value

Del U/Umf	Hs/Dc	N, rpm	ρ_s/ρ_f	dp/Dc	product	R-exp	R-Cal	%dev
0.698	3.200	73.900	708.661	0.001	5116402.470	2.625	2.758	-5.05
1.037	3.200	73.900	708.661	0.001	5319125.534	2.766	2.849	-3.03
1.377	3.200	73.900	708.661	0.001	5468802.570	2.813	2.917	-3.71
1.716	3.200	73.900	708.661	0.001	5588224.109	2.875	2.971	-3.33
1.377	3.200	73.900	708.661	0.001	5468802.570	2.750	2.917	-6.07
1.377	4.400	73.900	708.661	0.001	3791788.824	2.250	2.141	4.83
1.377	5.000	73.900	708.661	0.001	3273401.033	2.060	1.892	8.18
1.377	3.200	73.900	708.661	0.001	5468802.570	2.813	2.917	-3.71
1.377	3.200	101.600	708.661	0.001	5382447.242	2.750	2.878	-4.66
1.377	3.200	121.200	708.661	0.001	5335183.190	2.750	2.857	-3.88
1.377	3.200	137.400	708.661	0.001	5301821.847	2.719	2.842	-4.52
1.377	3.200	121.200	708.661	0.001	5335183.190	2.750	2.857	-3.88
1.377	3.200	121.200	2968.504	0.002	2342173.905	1.625	1.426	12.25
1.377	3.200	121.200	2519.685	0.001	2989921.750	1.625	1.752	-7.83
1.377	3.200	121.200	708.661	0.001	5335183.190	2.750	2.857	-3.88
1.377	3.200	121.200	708.661	0.001	4319395.668	2.471	2.390	3.29
1.377	3.200	121.200	708.661	0.002	3548361.037	1.860	2.025	-8.85
1.377	3.200	121.200	708.661	0.002	2952201.112	1.563	1.734	-10.95

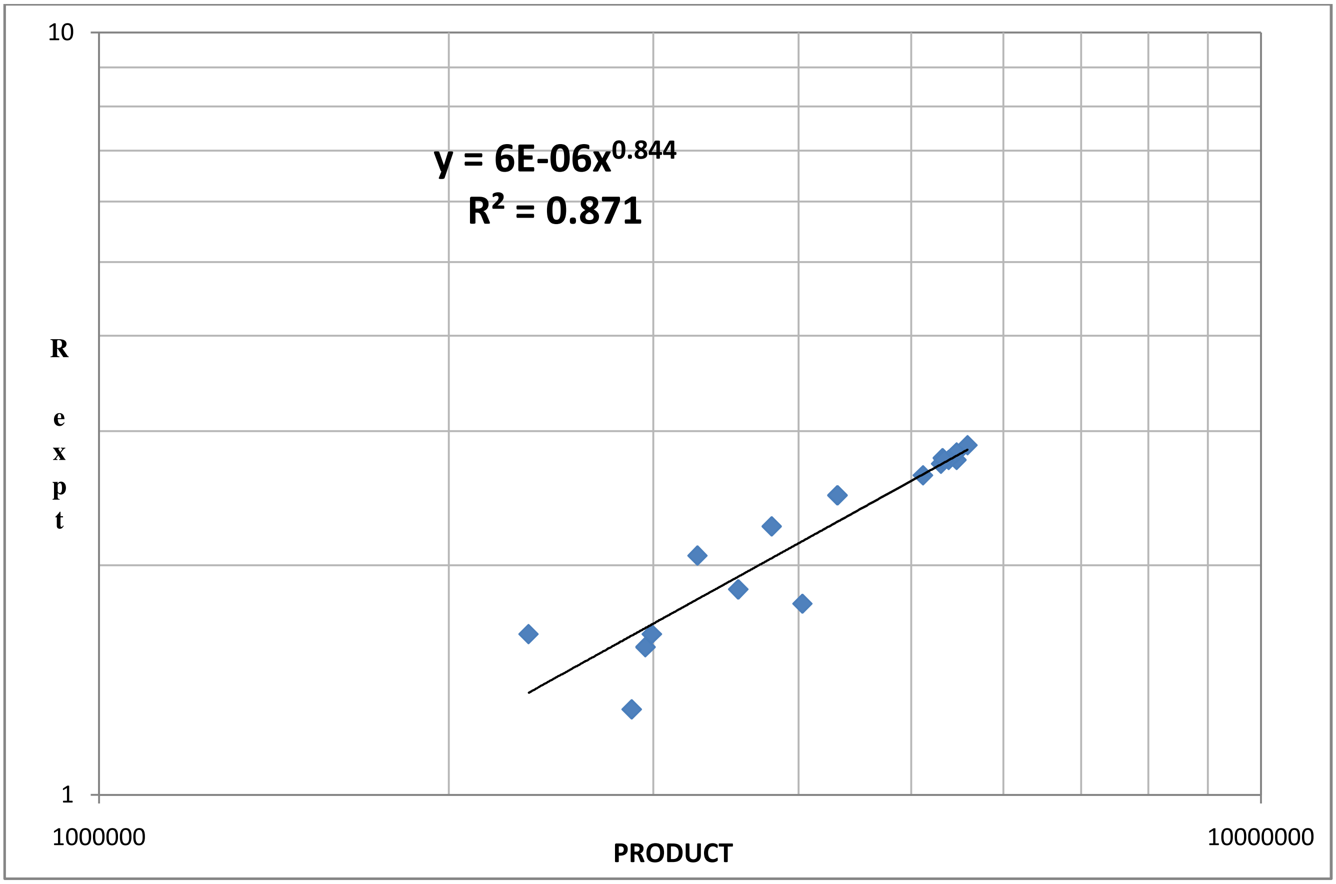


Figure 4.2.6 : CORRELATION PLOT OF BED EXPANSION RATIO AGAINST SYSTEM PARAMETERS

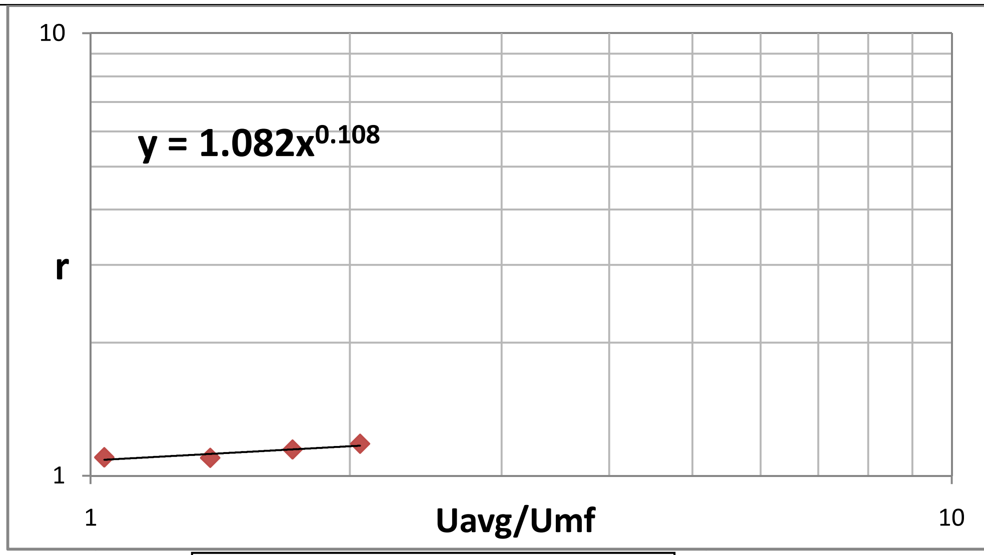
$$\boxed{R = 6E-06 \times \left(\frac{U_o - U_{mf}}{U_{mf}}\right)^{0.083} \left(\frac{H_s}{D_c}\right)^{-0.971} (N)^{-0.042} \left(\frac{\rho_s}{\rho_f}\right)^{-0.246} \left(\frac{d_p}{D_c}\right)^{-2.4064}}$$

4.2.2 FOR BED FLUCTUATION RATIO (r)

Exponent Of Individual Parameter :

Uavg/Umf	r
1.037351	1.1
1.37691	1.097561
1.716469	1.146341
2.056027	1.180723

r Vs (Uavg/Umf)

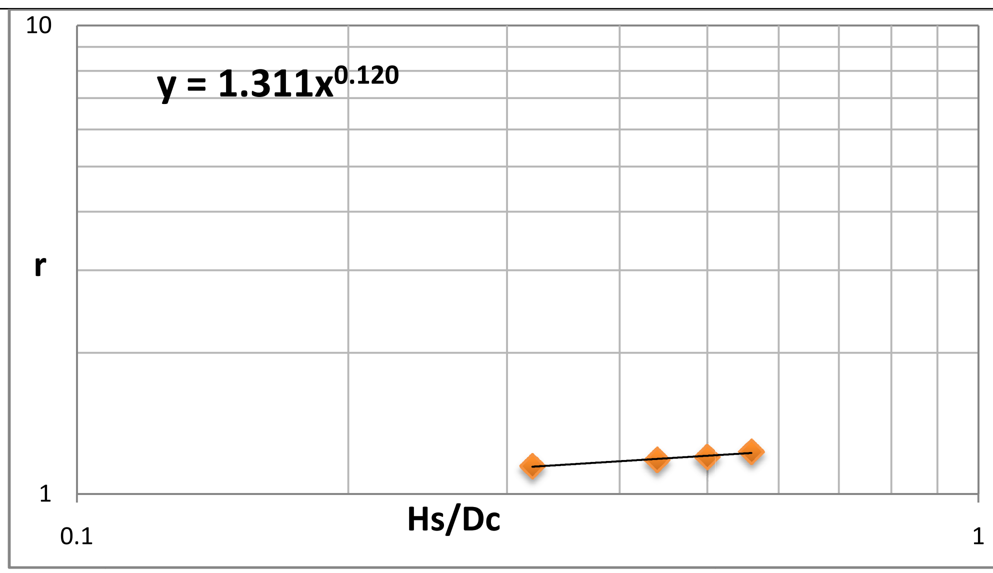


$r = 1.082(Uavg/Umf)^{0.108}$

Figure-4.2.7 : r Vs (Uavg/Umf)

Hs/Dc	r
0.32	1.146341
0.44	1.181818
0.5	1.2
0.56	1.230769

r Vs Hs/Dc

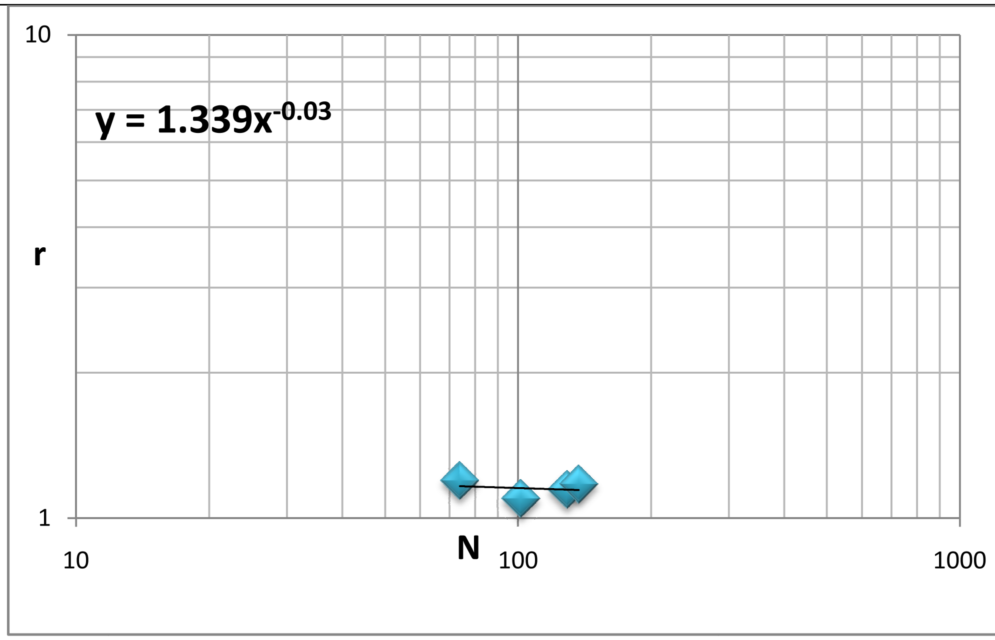


$r = 1.311 (Hs/Dc)^{0.120}$

Figure 4.2.8: r Vs Hs/Dc

N	r
73.9	1.195122
101.6	1.097561
129.2	1.146341
137.4	1.175

r Vs N

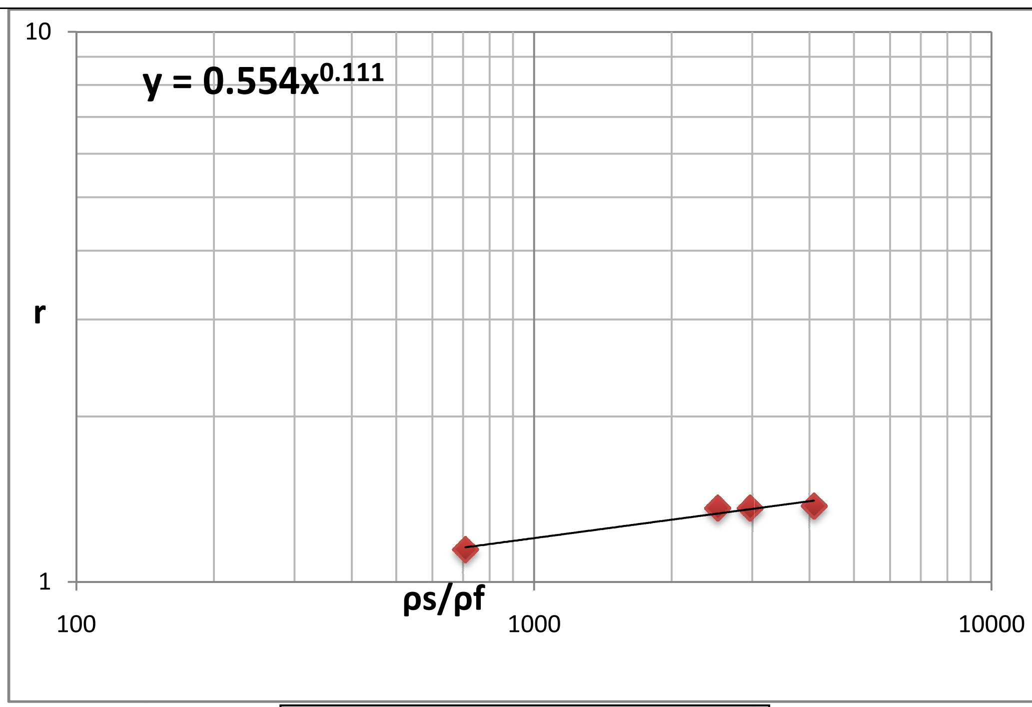


$r = 1.339N^{-0.03}$

Figure 4.2.9 : r Vs N

ρs/ρf	r
708.6614	1.146341
2968.504	1.363636
2519.685	1.363636
4094.488	1.375

r Vs (ρs/ρf)

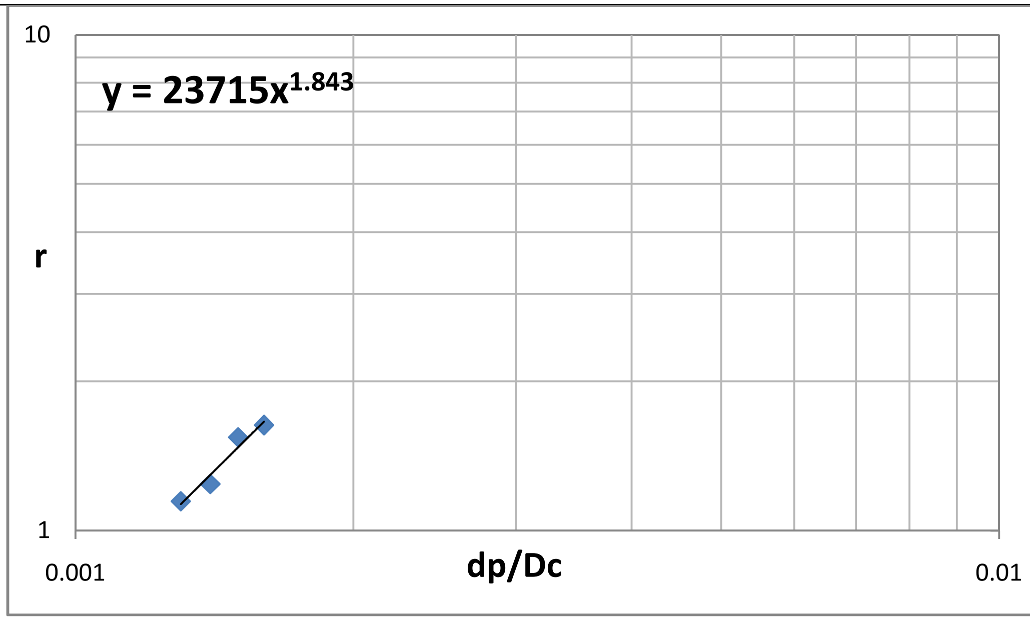


$r = 0.554\ (\rho s/\rho f)^{0.111}$

Figure 4.2.10 : r Vs (ρs/ρf)

dp/Dc	r
0.0013	1.146341
0.0014	1.24241
0.0015	1.542975
0.0016	1.631579

r Vs (dp/Dc)



$$r = 23715(dp/Dc)^{1.843}$$

Figure 4.2.11: r Vs (dp/Dc)

Table 3 Observed Data and Comparison of Calculated Value of Fluctuation Ratio 'r' With Experimental 'r' Value

Uavg/Umf	Hs/Dc	N, rpm	ρs/ρf	dp/Dc	product	r exp	r cal	%dev
1.037	0.320	101.600	708.661	0.001	0.0000075	1.100	1.135	-3.19
1.377	0.320	101.600	708.661	0.001	0.0000077	1.098	1.160	-5.66
1.716	0.320	101.600	708.661	0.001	0.0000079	1.146	1.179	-2.87
2.056	0.320	101.600	708.661	0.001	0.0000080	1.181	1.195	-1.24
1.377	0.320	129.200	708.661	0.001	0.0000077	1.146	1.154	-0.65
1.377	0.440	129.200	708.661	0.001	0.0000080	1.182	1.187	-0.42
1.377	0.500	129.200	708.661	0.001	0.0000081	1.200	1.200	-0.02
1.377	0.560	129.200	708.661	0.001	0.0000082	1.231	1.212	1.50
1.377	0.320	73.900	708.661	0.001	0.0000078	1.195	1.167	2.31
1.377	0.320	101.600	708.661	0.001	0.0000077	1.098	1.160	-5.66
1.377	0.320	129.200	708.661	0.001	0.0000077	1.146	1.154	-0.65
1.377	0.320	137.400	708.661	0.001	0.0000076	1.175	1.152	1.93
1.377	0.320	129.200	708.661	0.001	0.0000077	1.146	1.154	-0.65
1.377	0.320	129.200	2968.504	0.002	0.0000117	1.364	1.550	-13.68
1.377	0.320	129.200	2519.685	0.001	0.0000101	1.364	1.400	-2.68
1.377	0.320	129.200	4094.488	0.001	0.0000080	1.375	1.191	13.37
1.377	0.320	129.200	708.661	0.001	0.0000077	1.146	1.154	-0.65
1.377	0.320	129.200	708.661	0.001	0.0000088	1.242	1.270	-2.20
1.377	0.320	129.200	708.661	0.002	0.0000100	1.543	1.388	10.04
1.377	0.320	129.200	708.661	0.002	0.0000112	1.632	1.509	7.52

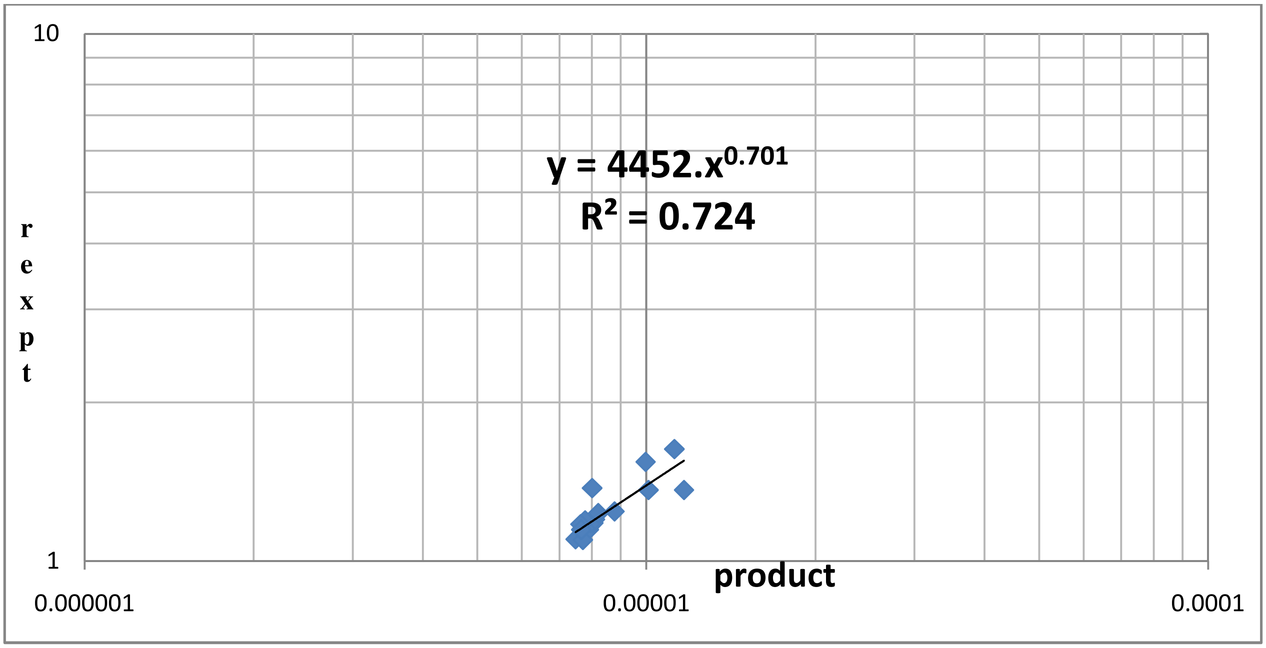


Figure-4.2.12 : CORRELATION PLOT OF BED FLUCTUATION RATIO AGAINST SYSTEM PARAMETERS

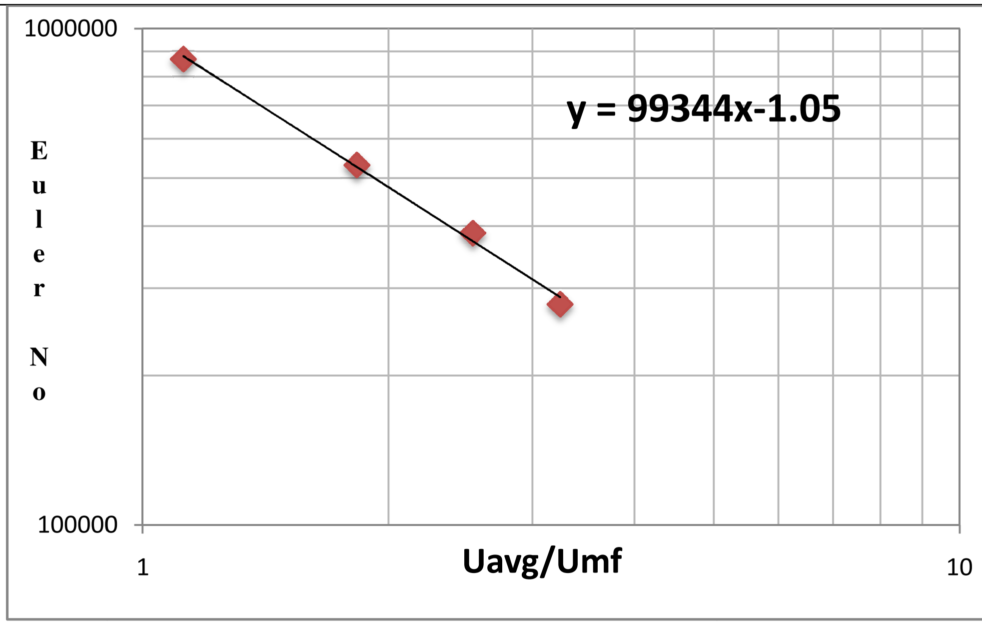
$$r = 4452\times\left(\frac{U_o - U_{mf}}{U_{mf}}\right)^{0.076}\left(\frac{H_s}{D_c}\right)^{0.084}(N)^{-0.021}\left(\frac{\rho_s}{\rho_f}\right)^{0.078}\left(\frac{d_p}{D_c}\right)^{1.292}$$

4.2.3 FOR Euler's Number

Exponent Of Individual Parameter :

Uavg/Umf	Euler No
1.122241	867923
1.829655	530659.4
2.537068	387169.1
3.244482	278301.4

E.N Vs Uavg/Umf

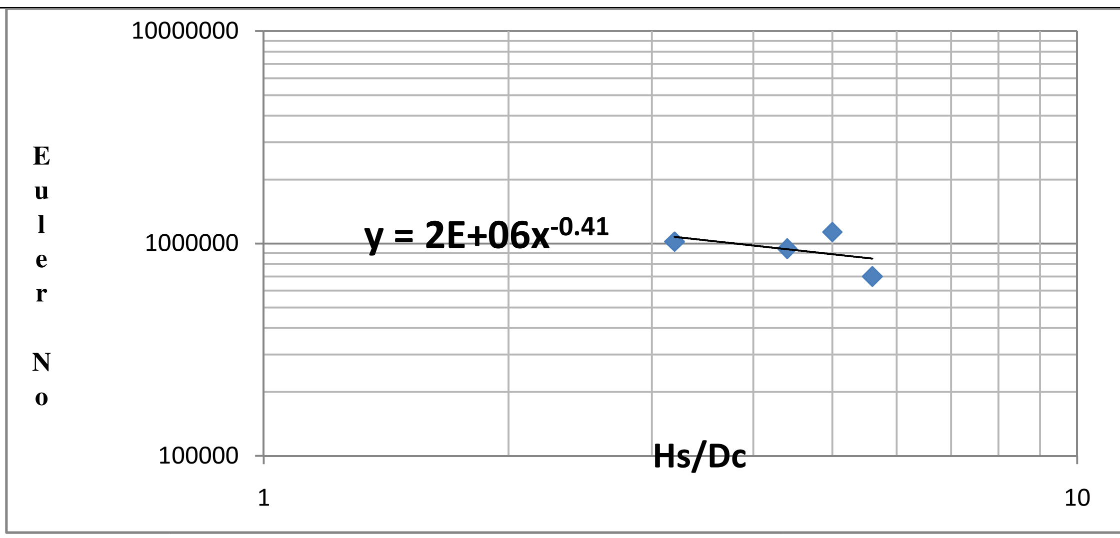


E.N = 99344 (Uavg/Umf)-1.05

Figure-4.2.13 : E.N Vs Uavg/Umf

Hs/Dc	Euler No
3.2	1018858
4.4	943386.6
5	1132064
5.6	698106.1

E.N Vs Hs/Dc

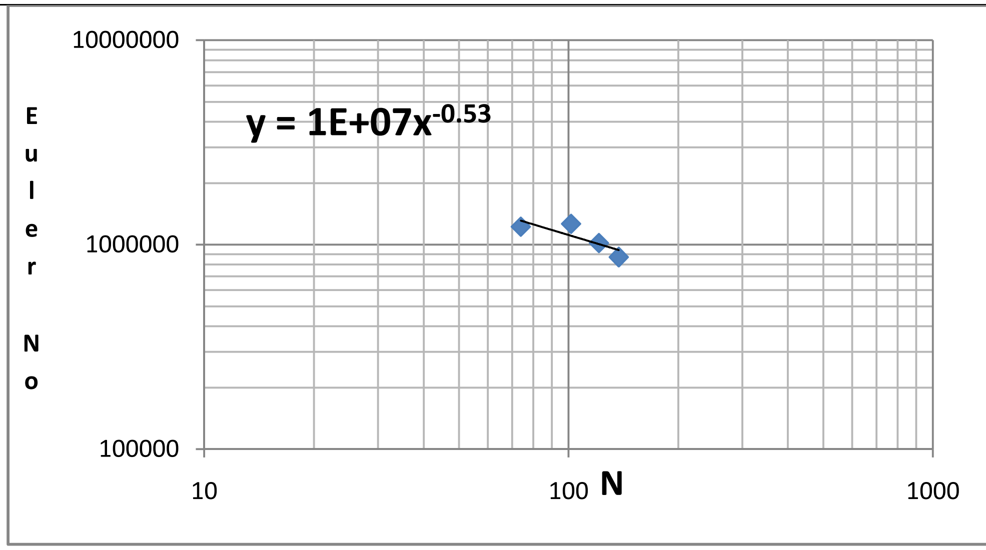


E.N = 2E+06(Hs/Dc)$^{-0.41}$

Figure-4.2.14 : E.N Vs Hs/Dc

N	Euler No
73.9	1226403
101.6	1264138
121.2	1018858
137.4	867915.7

E.N Vs N

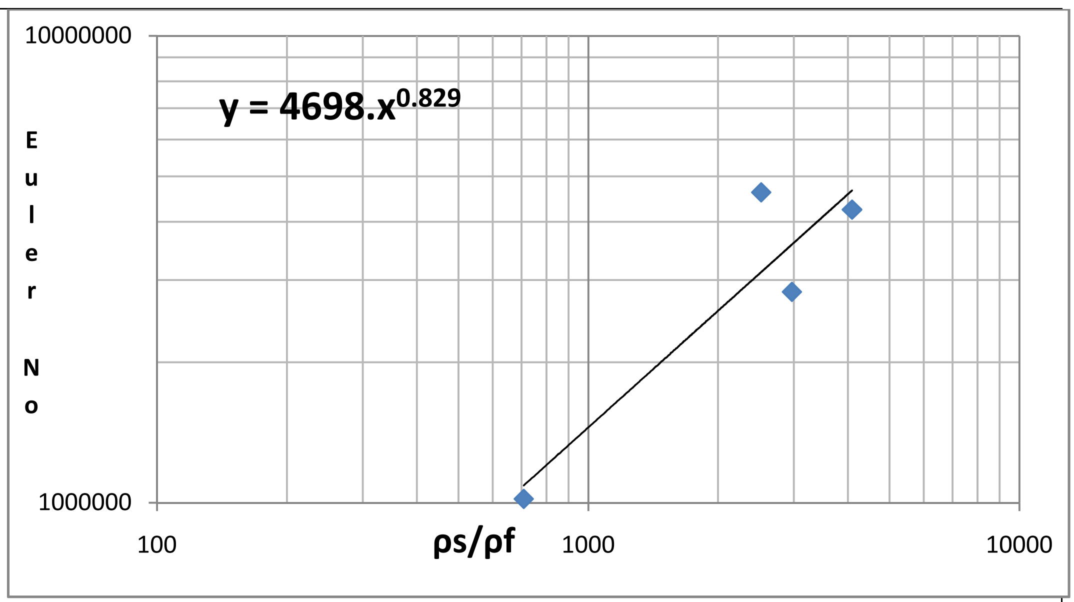


$$E.N = 1E{+}07N^{-0.53}$$

Figure-4.2.15 : E.N Vs N

ρs/ρf	Euler No
708.6614	1018858
2968.504	2830160
2519.685	4622595
4094.488	4245240

E.N. Vs (ρs/ρf)

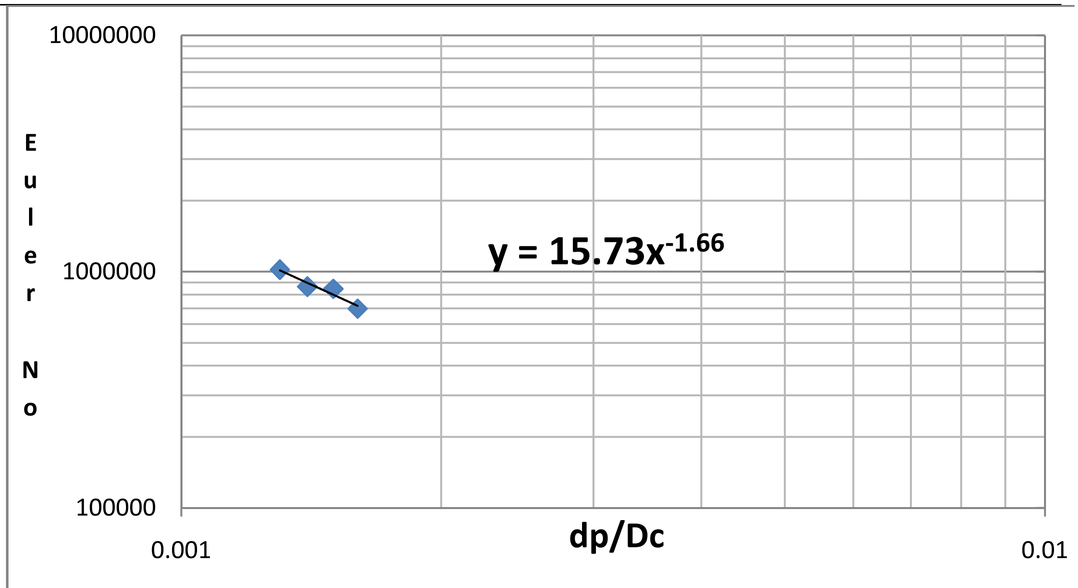


$$E.N = 4698(\rho s/\rho f)^{0.829}$$

Figure-4.2.16 : E.N Vs (ρs/ρf)

dp/Dc	Euler No
0.0013	1018858
0.0014	863433
0.0015	845274
0.0016	698106.1

E.N Vs (dp/Dc)



$$E.N = 15.73(dp/Dc)^{-1.66}$$

Figure-4.2.17 : E.N Vs (dp/Dc)

Table 4 - Observed Data & Comparison of Calculated Value of Euler Number 'EN' With Experimental 'EN' Value

Uavg/Umf	Hs/Dc	N, rpm	ρs/ρf	dp/Dc	product	E No.exp	E No. cal	%dev
1.122	3.200	137.400	708.661	0.001	576810.103	867923.002	951521.999	-9.63
1.830	3.200	137.400	708.661	0.001	345251.615	530659.444	547467.842	-3.17
2.537	3.200	137.400	708.661	0.001	244948.358	387169.131	378285.519	2.29
3.244	3.200	137.400	708.661	0.001	189199.798	278301.397	286437.587	-2.92
1.122	3.200	121.200	708.661	0.001	616466.439	1018857.575	1022160.066	-0.32
1.122	4.400	121.200	708.661	0.001	541010.049	943386.643	888072.839	5.86
1.122	5.600	121.200	708.661	0.001	490076.455	698106.116	798363.363	-14.36
1.122	3.200	73.900	708.661	0.001	801279.948	1226402.636	1355695.357	-10.54
1.122	3.200	101.600	708.661	0.001	676880.747	1264138.102	1130441.371	10.58
1.122	3.200	121.200	708.661	0.001	616466.439	1018857.575	1022160.066	-0.32
1.122	3.200	137.400	708.661	0.001	576810.103	867915.712	951521.999	-9.63
1.122	3.200	121.200	708.661	0.001	616466.439	1018857.575	1022160.066	-0.32
1.122	3.200	121.200	2968.504	0.002	1593910.208	2830159.930	2843413.452	-0.47
1.122	3.200	121.200	708.661	0.001	616466.439	1018857.575	1022160.066	-0.32
1.122	3.200	121.200	708.661	0.001	545108.387	863433.000	895320.419	-3.69
1.122	3.200	121.200	708.661	0.002	486120.474	845274.000	791424.771	6.37
1.122	3.200	121.200	708.661	0.002	436733.224	698106.116	705178.929	-1.01

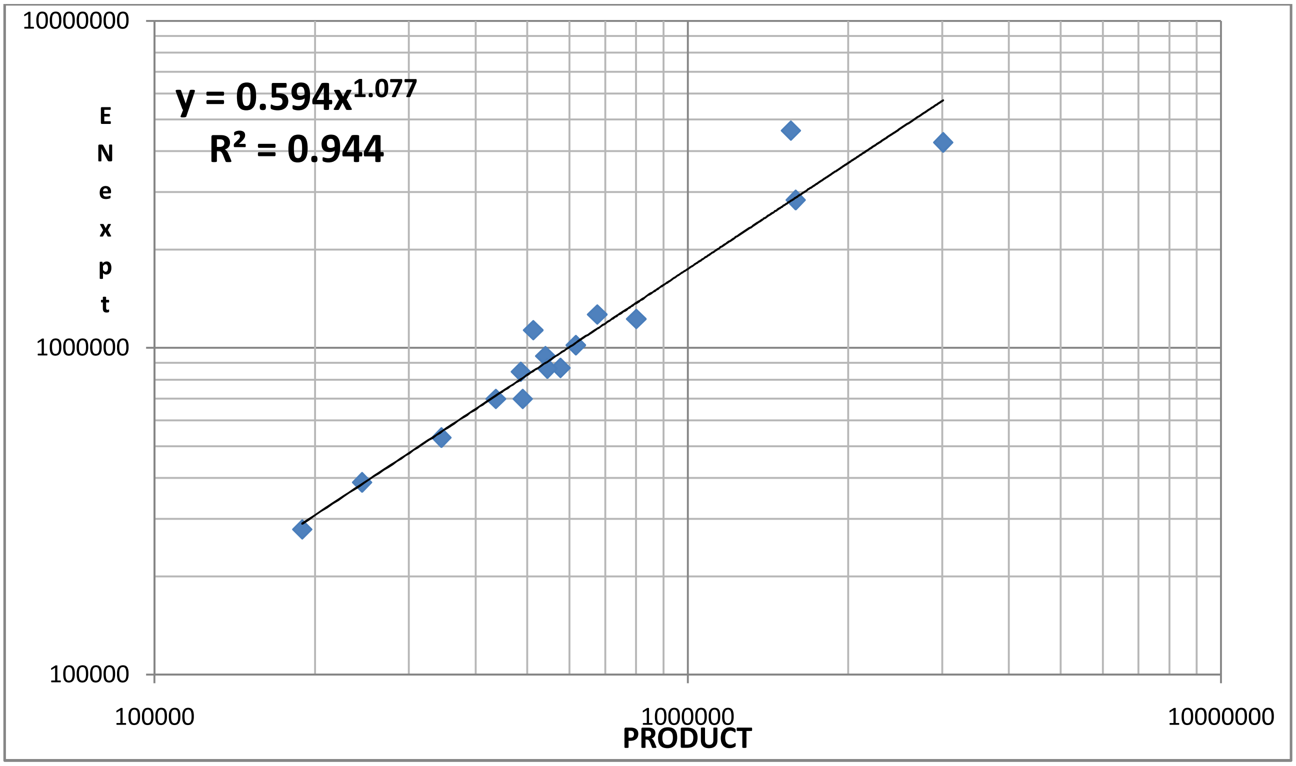


Figure-4.2.13 : CORRELATION PLOT OF EULER NUMBER AGAINST SYSTEM PARAMETERS

$$\left(\frac{\Delta P}{U^2\rho_f}\right) = 0.594 \times \left(\frac{Uavg}{U_{mf}}\right)^{-1.131} \left(\frac{H_s}{D_c}\right)^{-0.442} (N)^{-0.571} \left(\frac{\rho_s}{\rho_f}\right)^{0.893} \left(\frac{d_p}{D_c}\right)^{-1.788}$$

4.3 FINAL RESULTS

The correlations developed from the observed experimental data are as follows.

$$R = 6E-06 \times \left(\frac{U_o - U_{mf}}{U_{mf}}\right)^{0.083} \left(\frac{H_s}{D_c}\right)^{-0.971} (N)^{-0.042} \left(\frac{\rho_s}{\rho_f}\right)^{-0.246} \left(\frac{d_p}{D_c}\right)^{-2.4064} \quad \textbf{(2)}$$

$$r = 4452 \times \left(\frac{U_o - U_{mf}}{U_{mf}}\right)^{0.076} \left(\frac{H_s}{D_c}\right)^{0.084} (N)^{-0.021} \left(\frac{\rho_s}{\rho_f}\right)^{0.078} \left(\frac{d_p}{D_c}\right)^{1.292} \quad \textbf{(3)}$$

$$\left(\frac{\Delta P}{U^2 \rho_f}\right) = 0.594 \times \left(\frac{Uavg}{U_{mf}}\right)^{-1.131} \left(\frac{H_s}{D_c}\right)^{-0.442} (N)^{-0.571} \left(\frac{\rho_s}{\rho_f}\right)^{0.893} \left(\frac{d_p}{D_c}\right)^{-1.788} \quad (4)$$

4.4 DISCUSSION:

With different system parameters the dependent variables i.e. the fluidization characteristics such as '***R***' , '***r***' & Euler's No. vary differently. With increase in Uo (superficial velocity) both the bed expansion and fluctuation ratios increase, but the Euler's No. decreases with increase in Uo. Again with increase in bed height (Hs) the bed expansion increases whereas the bed fluctuation ratio and Euler's Nos. are found to decrease. All the three dependent variables i.e '***R***' , '***r***' & Euler's No. are observed to be decreasing with the increased speed of the stirrer.

Apart from this it was also observed that sometimes the fluidization was not proper due to the cohesive property of the particles. Special care should be taken while conducting the experiment to prevent the excess fluctuation in bed pressure drop so as to get the proper fluidization.

The correlation obtained for bed expansion ratio (R) counts a deviation of +13 to -11% between calculated and experimentally observed values which is reasonable. The correlation obtained for bed fluctuation ratio (r) counts a deviation of +13 to -13% between calculated and observed value . The correlation obtained for Euler's No ($\Delta p/Uo^2\rho f$) counts a deviation of +10 to -14% between calculated and observed value of Euler Number. We can consider this parameter for fluidization as these deviations are reasonable.

CHAPTER 5

Conclusion:

It was observed that the %deviation between the calculated and experimentally observed values of bed expansion, bed fluctuation and Euler number are quite reasonable which indicates the applicability of these developed correlations over a wide range of parameters. From the developed correlation it was found that the expansion ratio 'R' increases with superficial velocity Uo, but with other parameter i.e. static bed height (Hs),stirrer speed N ,particle density and particle size dp it decreases. The fluctuation ratio 'r' decreases with increase speed of stirrer,but with the remaining parameter it increases. The Euler No. found to decrease with all the parameter except the particle density where it follows a reverse trend.

With the view of satisfactory fluidization achieved by using a stirrer in the fluidized bed, in terms of obtained result, this method can be applicable in any industry with little medication as per the requirement to perform in pilot scale where the fine particle can be efficiently handled. The developed system can be used for drying of fine particles. This may also used in fluidized bed reactor where catalysts are mainly smaller in size to provide large surface area for reaction to occur. Apart from this, it can be used in **pharmaceutical industry** for different purposes. This method can also be extended to nano scale where different mode of mechanical disturbance such as vibration , rotating, use of sound amplifier may be use to break the cohesiveness of particle. Further this method may be used in CFD analysis for different fluidization processes.

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APPENDIX

Material-Talcum Powder (dp-65µm)

At-73.9 rpm

Flow Rate (lpm)	h1(cm)	h2(cm)	(h1-h2)=B2-C2	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	31	31	0	0	0	16	16	1	1
0.5	31.9	30	1.9	0.004244	295.279	16.2	16.2	1	1.0125
1	32.5	29.5	3	0.008489	466.2301	16.3	16.3	1	1.01875
2	33	29	4	0.016978	621.6401	25	23	1.086957	1.5
3	34.5	28	6.5	0.025467	1010.165	38	5	7.6	1.34375
4	34.8	27.5	7.3	0.033956	1134.493	41	38	1.078947	2.46875
5	35	27.2	7.8	0.042445	1212.198	44	40	1.1	2.625
6	35.2	27	8.2	0.050934	1274.362	48	40.5	1.185185	2.765625
7	35.3	26.9	8.4	0.059423	1305.444	49	41	1.195122	2.8125
8	35.5	26.8	8.7	0.067912	1352.067	50	42	1.190476	2.875
9	35.9	26.5	9.4	0.076401	1460.854	52	43	1.209302	2.96875
10	36	26.4	9.6	0.08489	1491.936	53	44	1.204545	3.03125
9	35.5	26.8	8.7	0.076401	1352.067	50	42	1.190476	2.875
8	35	27	8	0.067912	1243.28	49	41	1.195122	2.8125
7	34.9	27.2	7.7	0.059423	1196.657	46	40	1.15	2.6875
6	34.8	27.5	7.3	0.050934	1134.493	45	39	1.153846	2.625
5	34.5	27.8	6.7	0.042445	1041.247	42	37	1.135135	2.46875
4	34.4	28	6.4	0.033956	994.6241	41	36.5	1.123288	2.421875
3	34	28	6	0.025467	932.4601	40	36	1.111111	2.375
2	33.9	28.3	5.6	0.016978	870.2961	38	35	1.085714	2.28125
1	33.2	29	4.2	0.008489	652.7221	26	26	1	1.625
0.5	32.5	29.5	3	0.004244	466.2301	17	17	1	1.0625
0	31	31	0	0	0	16	16	1	1

At-101.6rpm

Flow	h_1(cm)	h_2(cm)	(Δh)	Usup(m/sec)	ΔP (N/m^2)	Hmax(cm)	Hmin(cm)	r	R
0	31	31	0	0	0	16	16	1	1
1	32.8	29.2	3.6	0.008489	559.4761	17	17	1	1.0625
2	34	28.5	5.5	0.016978	854.7551	34	33	1.030303	2.09375
3	34.5	27.8	6.7	0.025467	1041.247	39	34	1.147059	2.28125
4	34.6	27.5	7.1	0.033956	1103.411	41	37	1.108108	2.4375
5	35	27	8	0.042445	1243.28	42	38	1.105263	2.5
6	35.2	26.9	8.3	0.050934	1289.903	44	40	1.1	2.625
7	35.2	26.8	8.4	0.059423	1305.444	45	41	1.097561	2.6875
8	35.5	26.5	9	0.067912	1398.69	47	41	1.146341	2.75
9	35.8	26.2	9.6	0.076401	1491.936	49	41.5	1.180723	2.828125
10	36.2	25.9	10.3	0.08489	1600.723	50	42	1.190476	2.875
9	35.7	26.3	9.4	0.076401	1460.854	47	41	1.146341	2.75
8	35.5	26.8	8.7	0.067912	1352.067	45	40	1.125	2.65625
7	35	27	8	0.059423	1243.28	44	39	1.128205	2.59375
6	35	27.2	7.8	0.050934	1212.198	43	38	1.131579	2.53125
5	34.8	27.5	7.3	0.042445	1134.493	41	37	1.108108	2.4375
4	34.5	27.9	6.6	0.033956	1025.706	39	36	1.083333	2.34375
3	34.1	28	6.1	0.025467	948.0011	37	35.8	1.03352	2.275
2	34	28.1	5.9	0.016978	916.9191	36	34	1.058824	2.1875
1	33.8	28.5	5.3	0.008489	823.6731	31	30	1.033333	1.90625
0	31	31	0	0	0	16	16	1	1

At-121.2µm

Flow Rate (lpm)	h_1(cm)	h_2(cm)	(h1-h2)	Usup(m/sec)	ΔP (N/m^2)	Hmax(cm)	Hmin(cm)	r	R
0	31.4	30	0	0	0	16	16	1	1
1	32.5	29	2.1	0.008489	326.361	18.5	18.5	1	1.15625
2	34	27.8	4.8	0.016978	745.9681	37	33.5	1.104478	2.203125
3	34.2	27.4	5.4	0.025467	839.2141	39	35	1.114286	2.3125
4	34.4	27	6	0.033956	932.4601	42	37	1.135135	2.46875
5	34.7	26.9	6.4	0.042445	994.6241	44	38	1.157895	2.5625
6	34.9	26.8	6.7	0.050934	1041.247	45.5	39	1.166667	2.640625
7	35	26.6	7	0.059423	1087.87	47	41	1.146341	2.75
8	35.2	26.4	7.4	0.067912	1150.034	48	41.5	1.156627	2.796875
9	35.4	26.2	7.8	0.076401	1212.198	49.5	42	1.178571	2.859375
10	35.6	26	8.2	0.08489	1274.362	50	42	1.190476	2.875
9	35.5	26.1	8	0.076401	1243.28	48	41.5	1.156627	2.796875
8	35.2	26.6	7.2	0.067912	1118.952	46.5	40	1.1625	2.703125
7	34.9	26.8	6.7	0.059423	1041.247	45	39	1.153846	2.625
6	34.8	26.9	6.5	0.050934	1010.165	43.5	37.5	1.16	2.53125
5	34.3	27.3	5.6	0.042445	870.2961	42	36.5	1.150685	2.453125
4	34.1	27.5	5.2	0.033956	808.1321	41	36	1.138889	2.40625
3	33.9	27.8	4.7	0.025467	730.4271	40	35	1.142857	2.34375
2	33.7	28	4.3	0.016978	668.2631	38	34	1.117647	2.25
1	33.4	28.2	3.8	0.008489	590.5581	29	29	1	1.8125
0	31.4	30	0	0	0	16	16	1	1

At 137.4 rpm

Flow Rate(lpm)	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	ΔP (N/m^2)	Hmax(cm)	Hmin(cm)	r	R
0	31.9	29.8	0	0	0	16	16	1	1
1	32	29.6	0.3	0.008489	46.62301	18	18	1	1.125
2	34.2	29	3.1	0.016978	481.7711	27	24	1.125	1.59375
3	34.2	27.5	4.6	0.025467	714.8861	41	35.5	1.15493	2.390625
4	34.3	27.2	5	0.033956	777.0501	43	38	1.131579	2.53125
5	34.8	27	5.7	0.042445	885.8371	45	39	1.153846	2.625
6	34.9	26.9	5.9	0.050934	916.9191	46	40	1.15	2.6875
7	35.2	26.5	6.6	0.059423	1025.706	47	40	1.175	2.71875
8	35.4	26.2	7.1	0.067912	1103.411	48	41	1.170732	2.78125
9	35.5	26	7.4	0.076401	1150.034	49	42	1.166667	2.84375
10	36.3	25.5	8.7	0.08489	1352.067	51	44	1.159091	2.96875
9	35.4	26.2	7.1	0.076401	1103.411	47	44	1.068182	2.84375
8	35	26.5	6.4	0.067912	994.6241	45	40	1.125	2.65625
7	34.9	26.9	5.9	0.059423	916.9191	44	39.5	1.113924	2.609375
6	34.6	27	5.5	0.050934	854.7551	43	39	1.102564	2.5625
5	34.4	27.2	5.1	0.042445	792.5911	41	38	1.078947	2.46875
4	34.2	27.5	4.6	0.033956	714.8861	40	37	1.081081	2.40625
3	34	27.8	4.1	0.025467	637.1811	39	36	1.083333	2.34375
2	33.8	28	3.7	0.016978	575.0171	37	35	1.057143	2.25
1	33.4	28.2	3.1	0.008489	481.7711	33	33	1	2.0625
0	31.9	29.8	0	0	0	16	16	1	1

Hs=22cm.At-121.2rpm

Flow Rate(lpm)	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	28	27.5	0	0	0	22	22	1	1.375
1	29	26.5	2	0.008489	310.82	24	24	1	1.5
2	30	26	3.5	0.016978	543.9351	24.5	24.5	1	1.53125
3	30.5	25	5	0.025467	777.0501	27	24.5	1.102041	1.609375
4	31	24.5	6	0.033956	932.4601	30	25	1.2	1.71875
5	32	24	7.5	0.042445	1165.575	31	25	1.24	1.75
6	32.5	23	9	0.050934	1398.69	36	32	1.125	2.125
7	33	22.5	10	0.059423	1554.1	39	33	1.181818	2.25
8	33.5	22	11	0.067912	1709.51	44	35	1.257143	2.46875
9	34	21	12.5	0.076401	1942.625	53	42	1.261905	2.96875
10	35	20.5	14	0.08489	2175.74	57	49	1.163265	3.3125
9	33.5	21	12	0.076401	1864.92	53	47	1.12766	3.125
8	32.5	23	9	0.067912	1398.69	50	46	1.086957	3
7	32	23.5	8	0.059423	1243.28	49	44	1.113636	2.90625
6	31.5	24	7	0.050934	1087.87	47	43	1.093023	2.8125
5	31	24	6.5	0.042445	1010.165	46	43	1.069767	2.78125
4	31	24.5	6	0.033956	932.4601	45	41	1.097561	2.6875
3	30	25	4.5	0.025467	699.3451	35	31	1.129032	2.0625
2	30	26	3.5	0.016978	543.9351	30	27	1.111111	1.78125
1	29	26.5	2	0.008489	310.82	24.5	24.5	1	1.53125
0	28	27.5	0	0	0	22	22	1	1.375

At Hs-25cm.121.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	28	27.5	0	0	0	25	25	1	1.5625
1	29	26.5	2	0.008489	310.82	26	26	1	1.625
2	30.5	25	5	0.016978	777.0501	31	27	1.148148	1.8125
3	31	24.5	6	0.025467	932.4601	32	28	1.142857	1.875
4	31.5	24	7	0.033956	1087.87	33	28	1.178571	1.90625
5	32	23	8.5	0.042445	1320.985	34	28.5	1.192982	1.953125
6	32	23	8.5	0.050934	1320.985	35	29	1.206897	2
7	32.5	22.5	9.5	0.059423	1476.395	36	30	1.2	2.0625
8	33	22	10.5	0.067912	1631.805	38	30	1.266667	2.125
9	34	21	12.5	0.076401	1942.625	39	31	1.258065	2.1875
10	35	20	14.5	0.08489	2253.445	56	46	1.217391	3.1875
9	34	21.5	12	0.076401	1864.92	53	46	1.152174	3.09375
8	33	22	10.5	0.067912	1631.805	51	46	1.108696	3.03125
7	32.5	22.5	9.5	0.059423	1476.395	50	45	1.111111	2.96875
6	32.5	23	9	0.050934	1398.69	49	44	1.113636	2.90625
5	31.5	24.5	6.5	0.042445	1010.165	46	43	1.069767	2.78125
4	31	25	5.5	0.033956	854.7551	44	41	1.073171	2.65625
3	30.5	25	5	0.025467	777.0501	42	39	1.076923	2.53125
2	30	26	3.5	0.016978	543.9351	35	32	1.09375	2.09375
1	29	27	1.5	0.008489	233.115	29	29	1	1.8125
0	28	27.5	0	0	0	27	27	1	1.6875

At Hs-28cm,121.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	34.2	33.5	2.88658E-15	0	4.49E-13	28	28	1	1
1	34.5	33.4	0.4	0.008489	62.16401	30	30	1	1.071429
2	36	32	3.3	0.016978	512.8531	30.5	30.5	1	1.089286
3	36.2	31.8	3.7	0.025467	575.0171	31	31	1	1.107143
4	36.5	31.5	4.3	0.033956	668.2631	37	31.5	1.174603	1.223214
5	36.8	31.2	4.9	0.042445	761.5091	38	32	1.1875	1.25
6	37	31	5.3	0.050934	823.6731	39	32.5	1.2	1.276786
7	37.2	30.8	5.7	0.059423	885.8371	40	32.5	1.230769	1.294643
8	37.3	30.5	6.1	0.067912	948.0011	41	32.5	1.261538	1.3125
9	37.5	30.5	6.3	0.076401	979.0831	43	32.5	1.323077	1.348214
10	37.5	30.5	6.3	0.08489	979.0831	48	33	1.454545	1.446429
9	37.5	30.5	6.3	0.076401	979.0831	45	33	1.363636	1.392857
8	37.2	30.7	5.8	0.067912	901.3781	44	33	1.333333	1.375
7	37	31	5.3	0.059423	823.6731	40	32	1.25	1.285714
6	36.8	31.1	5	0.050934	777.0501	40	32	1.25	1.285714
5	36.5	31.8	4	0.042445	621.6401	38	32	1.1875	1.25
4	36.2	32	3.5	0.033956	543.9351	36	31	1.16129	1.196429
3	36	33	2.3	0.025467	357.443	34	30.5	1.114754	1.151786
2	35	33.5	0.8	0.016978	124.328	30	30	1	1.071429
1	34.5	33.5	0.3	0.008489	46.62301	29	29	1	1.035714
0	34.2	33.5	2.88658E-15	0	4.49E-13	28	28	1	1

Talcum Powder (dp-80μm)

At 73.9 rpm,Hs-16cm

Flow Rate(lpm	h_1(cm)	h_2(cm)	(h1-h2)	Usup(m/sec)	ΔP (N/m^2)	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	16	16	1	1
1	37.5	36	2	0.008489	310.82	16.2	16.2	1	1.0125
2	38.1	35.5	3.1	0.016978	481.7711	17	17	1	1.0625
3	38.5	35	4	0.025467	621.6401	19	17.5	1.085714	1.140625
4	38.8	34.5	4.8	0.033956	745.9681	21	18	1.166667	1.21875
5	39.2	34.3	5.4	0.042445	839.2141	26	18.5	1.405405	1.390625
6	39.5	34	6	0.050934	932.4601	27	19	1.421053	1.4375
7	40	33.5	7	0.059423	1087.87	29	20	1.45	1.53125
8	40	33.5	7	0.067912	1087.87	30	20	1.5	1.5625
9	40.4	33	7.9	0.076401	1227.739	31	21	1.47619	1.625
10	41	32.5	9	0.08489	1398.69	31	21	1.47619	1.625
9	40.4	33	7.9	0.076401	1227.739	30	20.5	1.463415	1.578125
8	40	33.5	7	0.067912	1087.87	28	20	1.4	1.5
7	39.5	34	6	0.059423	932.4601	26	19	1.368421	1.40625
6	39	34.3	5.2	0.050934	808.1321	24	18.5	1.297297	1.328125
5	38.7	34.8	4.4	0.042445	683.8041	23	18	1.277778	1.28125
4	38.2	35	3.7	0.033956	575.0171	22	17.5	1.257143	1.234375
3	38	35.5	3	0.025467	466.2301	20	17	1.176471	1.15625
2	37.9	35.8	2.6	0.016978	404.0661	18	17	1.058824	1.09375
1	37	36.5	1	0.008489	155.41	17	17	1	1.0625

At 101.6rpm

Flow Rate(lpm	h_1(cm)	h_2(cm)	(h1-h2)	Usup(m/sec)	ΔP (N/m^2)	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	16	16	1	1
1	37.5	36	2	0.008489	310.82	17	17	1	1.0625
2	38.3	35.5	3.3	0.016978	512.8531	19	17.5	1.085714	1.140625
3	38.5	35	4	0.025467	621.6401	21	18	1.166667	1.21875
4	39	34.5	5	0.033956	777.0501	23	18	1.277778	1.28125
5	39.2	34.2	5.5	0.042445	854.7551	25	19	1.315789	1.375
6	39.5	33.8	6.2	0.050934	963.5421	29	19	1.526316	1.5
7	40	33.5	7	0.059423	1087.87	30	19	1.578947	1.53125
8	40.3	33	7.8	0.067912	1212.198	31	19	1.631579	1.5625
9	40.5	33	8	0.076401	1243.28	32	19	1.684211	1.59375
10	41.5	32.5	9.5	0.08489	1476.395	32	19	1.684211	1.59375
9	40.5	33	8	0.076401	1243.28	31	19	1.631579	1.5625
8	40	33.5	7	0.067912	1087.87	30	19	1.578947	1.53125
7	39.8	34	6.3	0.059423	979.0831	30	19	1.578947	1.53125
6	39.2	34	5.7	0.050934	885.8371	29	19	1.526316	1.5
5	39	34.5	5	0.042445	777.0501	28	18.5	1.513514	1.453125
4	38.5	34.8	4.2	0.033956	652.7221	26	18	1.444444	1.375
3	38.3	35.2	3.6	0.025467	559.4761	23	18	1.277778	1.28125
2	38	35.5	3	0.016978	466.2301	20	17	1.176471	1.15625
1	37.5	36	2	0.008489	310.82	17	17	1	1.0625
0	36.5	37	0	0	0	16	16	1	1

At 121.2rpm-

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	16	16	1	1
1	37.2	36	1.7	0.008489	264.197	17	17	1	1.0625
2	38	35.5	3	0.016978	466.2301	23	17	1.352941	1.25
3	38.2	35	3.7	0.025467	575.0171	25	17.5	1.428571	1.328125
4	38.6	34.8	4.3	0.033956	668.2631	28	18	1.555556	1.4375
5	39	34.2	5.3	0.042445	823.6731	29	18	1.611111	1.46875
6	39.4	34	5.9	0.050934	916.9191	30	18.5	1.621622	1.515625
7	39.6	33.6	6.5	0.059423	1010.165	31	19	1.631579	1.5625
8	40	33	7.5	0.067912	1165.575	32	19	1.684211	1.59375
9	40.3	32.8	8	0.076401	1243.28	33	19	1.736842	1.625
10	41	31.5	10	0.08489	1554.1	33	19	1.736842	1.625
9	40	32.8	7.7	0.076401	1196.657	31	19	1.631579	1.5625
8	40	33	7.5	0.067912	1165.575	29	19	1.526316	1.5
7	39.5	34	6	0.059423	932.4601	28	19	1.473684	1.46875
6	39	34	5.5	0.050934	854.7551	27	18	1.5	1.40625
5	38.8	34.3	5	0.042445	777.0501	25	18	1.388889	1.34375
4	38.5	35	4	0.033956	621.6401	24	17.5	1.371429	1.296875
3	38	35.2	3.3	0.025467	512.8531	23	17.5	1.314286	1.265625
2	37.5	35.5	2.5	0.016978	388.5251	22	17	1.294118	1.21875
1	37.6	36	2.1	0.008489	326.361	19	16.5	1.151515	1.109375
0	36.5	37	0	0	0	16	16	1	1

At 137.4rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	16	16	1	1
1	37.2	36	1.7	0.008489	264.197	16.5	16.5	1	1.03125
2	38	35	3.5	0.016978	543.9351	24	17	1.411765	1.28125
3	38.5	35	4	0.025467	621.6401	28	17.5	1.6	1.421875
4	39	34.5	5	0.033956	777.0501	29	18	1.611111	1.46875
5	39	34	5.5	0.042445	854.7551	29	18	1.611111	1.46875
6	39.5	34	6	0.050934	932.4601	30	18.5	1.621622	1.515625
7	40	33.5	7	0.059423	1087.87	30	18.5	1.621622	1.515625
8	40.3	33	7.8	0.067912	1212.198	31	18.5	1.675676	1.546875
9	41	32.5	9	0.076401	1398.69	31	19	1.631579	1.5625
10	42	31	11.5	0.08489	1787.215	31	20	1.55	1.59375
9	40.5	32.5	8.5	0.076401	1320.985	30	19.5	1.538462	1.546875
8	40	33	7.5	0.067912	1165.575	29	19	1.526316	1.5
7	39.5	33.5	6.5	0.059423	1010.165	26	18.5	1.405405	1.390625
6	39	34	5.5	0.050934	854.7551	25	18	1.388889	1.34375
5	39	34.3	5.2	0.042445	808.1321	25	17.5	1.428571	1.328125
4	38.5	35	4	0.033956	621.6401	24	17	1.411765	1.28125
3	38	35.5	3	0.025467	466.2301	22	17	1.294118	1.21875
2	37.7	35.8	2.4	0.016978	372.984	22	16.5	1.333333	1.203125
1	37.5	36	2	0.008489	310.82	20	16	1.25	1.125
0	36.5	37	0	0	0	16	16	1	1

At Hs-18cm,121.2 rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	18	18	1	1
1	38	35.5	3	0.008489	466.2301	23	18	1.277778	1.138889
2	38.3	35.2	3.6	0.016978	559.4761	23.5	18.5	1.27027	1.166667
3	39	34.5	5	0.025467	777.0501	24	18.5	1.297297	1.180556
4	39.3	34	5.8	0.033956	901.3781	25	19	1.315789	1.222222
5	39.8	33.5	6.8	0.042445	1056.788	26	19.5	1.333333	1.263889
6	40	33	7.5	0.050934	1165.575	27	19.5	1.384615	1.291667
7	40.2	33	7.7	0.059423	1196.657	31	20	1.55	1.416667
8	40.5	32.8	8.2	0.067912	1274.362	33	20	1.65	1.472222
9	41	32.2	9.3	0.076401	1445.313	37	20	1.85	1.583333
10	42	31.8	10.7	0.08489	1662.887	37	20	1.85	1.583333
9	41	32.8	8.7	0.076401	1352.067	32	20	1.6	1.444444
8	40.8	33	8.3	0.067912	1289.903	31	20	1.55	1.416667
7	40	33.5	7	0.059423	1087.87	30	20	1.5	1.388889
6	39.5	34	6	0.050934	932.4601	29	20	1.45	1.361111
5	39.3	34	5.8	0.042445	901.3781	27	20	1.35	1.305556
4	39	34.5	5	0.033956	777.0501	26	20	1.3	1.277778
3	38.5	35	4	0.025467	621.6401	23	19	1.210526	1.166667
2	38	35.3	3.2	0.016978	497.3121	22	19	1.157895	1.138889
1	37.5	36	2	0.008489	310.82	19.5	19	1.026316	1.069444
0	36.5	37	0	0	0	18	18	1	1

At Hs-21cm,121.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.5	37	0	0	0	21	21	1	1
1	38	35.8	2.7	0.008489	419.6071	22	21	1.047619	1.02381
2	38.5	35	4	0.016978	621.6401	23	21	1.095238	1.047619
3	39	34.5	5	0.025467	777.0501	24	21	1.142857	1.071429
4	39	34	5.5	0.033956	854.7551	26	21	1.238095	1.119048
5	39.5	33.8	6.2	0.042445	963.5421	27	21.5	1.255814	1.154762
6	40	33.5	7	0.050934	1087.87	27	22	1.227273	1.166667
7	40.2	33	7.7	0.059423	1196.657	27	22	1.227273	1.166667
8	40.2	33	7.7	0.067912	1196.657	29	22	1.318182	1.214286
9	41	32	9.5	0.076401	1476.395	31	23	1.347826	1.285714
10	42.5	30.5	12.5	0.08489	1942.625	32	23	1.391304	1.309524
9	40.5	33	8	0.076401	1243.28	30	22	1.363636	1.238095
8	40.2	33	7.7	0.067912	1196.657	29	22	1.318182	1.214286
7	40	33.5	7	0.059423	1087.87	28	21.5	1.302326	1.178571
6	39.2	34	5.7	0.050934	885.8371	26	21	1.238095	1.119048
5	39	34.2	5.3	0.042445	823.6731	26	21	1.238095	1.119048
4	38.5	34.5	4.5	0.033956	699.3451	25	21	1.190476	1.095238
3	38	35.3	3.2	0.025467	497.3121	24	21	1.142857	1.071429
2	38	35.5	3	0.016978	466.2301	23	21	1.095238	1.047619
1	37.2	36	1.7	0.008489	264.197	21	21	1	1
0	36.5	37	0	0	0	21	21	1	1

Material-Alumina Powder (dp-75µm)

Hs-16cm,73.9rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.5	36	0	0	0	16	16	1	1
1	42	29	12.5	0.008489	1942.625	19.5	18.5	1.054054	1.1875
2	43	28.5	14	0.016978	2175.74	22	20	1.1	1.3125
3	43.3	28.2	14.6	0.025467	2268.986	23	20.5	1.121951	1.359375
4	43.5	28	15	0.033956	2331.15	25	21	1.190476	1.4375
5	44	28	15.5	0.042445	2408.855	25	21	1.190476	1.4375
6	44.2	27.5	16.2	0.050934	2517.642	27	22	1.227273	1.53125
7	44.3	27.5	16.3	0.059423	2533.183	28	22	1.272727	1.5625
8	45	27	17.5	0.067912	2719.675	30	22	1.363636	1.625
9	45	26.5	18	0.076401	2797.38	32	22	1.454545	1.6875
10	47.5	24	23	0.08489	3574.43	41	23	1.782609	2
9	44.5	27	17	0.076401	2641.97	33	22	1.5	1.71875
8	44	27.5	16	0.067912	2486.56	30	22	1.363636	1.625
7	44	27.5	16	0.059423	2486.56	29	22	1.318182	1.59375
6	44	28	15.5	0.050934	2408.855	28	21.5	1.302326	1.546875
5	44	28	15.5	0.042445	2408.855	27	21	1.285714	1.5
4	43.5	28.5	14.5	0.033956	2253.445	25	21	1.190476	1.4375
3	43	29	13.5	0.025467	2098.035	23	20	1.15	1.34375
2	43	29	13.5	0.016978	2098.035	21	20	1.05	1.28125
1	42	29.5	12	0.008489	1864.92	17	17	1	1.0625

At 101.6 rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36.2	35.8	5.66E-15	0	8.8E-13	16	16	1	1
1	42.5	29	13.1	0.008489	2035.871	17	17	1	1.0625
2	42.5	29	13.1	0.016978	2035.871	24	20	1.2	1.375
3	43.2	28.5	14.3	0.025467	2222.363	25	20	1.25	1.40625
4	43.5	28	15.1	0.033956	2346.691	26	21	1.238095	1.46875
5	44	28	15.6	0.042445	2424.396	27	21	1.285714	1.5
6	44	28	15.6	0.050934	2424.396	28	21.5	1.302326	1.546875
7	44.5	27.5	16.6	0.059423	2579.806	30	22	1.363636	1.625
8	44.5	27	17.1	0.067912	2657.511	31	22	1.409091	1.65625
9	45	27	17.6	0.076401	2735.216	32	22	1.454545	1.6875
10	45.5	26.5	18.6	0.08489	2890.626	32	22.5	1.422222	1.703125
9	45	27	17.6	0.076401	2735.216	31	22	1.409091	1.65625
8	44.5	27	17.1	0.067912	2657.511	31	22	1.409091	1.65625
7	44	27.5	16.1	0.059423	2502.101	30	22	1.363636	1.625
6	44	28	15.6	0.050934	2424.396	29	21.5	1.348837	1.578125
5	44	28	15.6	0.042445	2424.396	27	21	1.285714	1.5
4	43.5	28.5	14.6	0.033956	2268.986	25	21	1.190476	1.4375
3	43	29	13.6	0.025467	2113.576	24	20	1.2	1.375
2	43	29	13.6	0.016978	2113.576	22	20	1.1	1.3125
1	42.5	29.5	12.6	0.008489	1958.166	18	18	1	1.125
0	36.2	35.8	5.66E-15	0	8.8E-13	16	16	1	1

At 121.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	42.5	29	13.5	0.008489	2098.035	17	17	1	1.0625
2	43.2	28.8	14.4	0.016978	2237.904	22	20	1.1	1.3125
3	43.5	28.5	15	0.025467	2331.15	24	20.5	1.170732	1.390625
4	43.5	28	15.5	0.033956	2408.855	25	21	1.190476	1.4375
5	44	28	16	0.042445	2486.56	27	21	1.285714	1.5
6	44	28	16	0.050934	2486.56	28	21	1.333333	1.53125
7	44.5	27.5	17	0.059423	2641.97	30	22	1.363636	1.625
8	44.5	27	17.5	0.067912	2719.675	32	22	1.454545	1.6875
9	45	27	18	0.076401	2797.38	33	22	1.5	1.71875
10	45	26.5	18.5	0.08489	2875.085	36	22	1.636364	1.8125
9	44.5	27	17.5	0.076401	2719.675	32	22	1.454545	1.6875
8	44	27.5	16.5	0.067912	2564.265	31	22	1.409091	1.65625
7	44	28	16	0.059423	2486.56	30	22	1.363636	1.625
6	44	28	16	0.050934	2486.56	29	21	1.380952	1.5625
5	44	28	16	0.042445	2486.56	27	21	1.285714	1.5
4	43.5	28	15.5	0.033956	2408.855	25	21	1.190476	1.4375
3	43.2	28.5	14.7	0.025467	2284.527	22	21	1.047619	1.34375
2	43	29	14	0.016978	2175.74	21	20	1.05	1.28125
1	42	30	12	0.008489	1864.92	17	17	1	1.0625
0	36	36	0	0	0	16	16	1	1

At 137.4rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	43	29	14	0.008489	2175.74	19	18	1.055556	1.15625
2	43	29	14	0.016978	2175.74	22	19	1.157895	1.28125
3	43.2	28.5	14.7	0.025467	2284.527	24	20	1.2	1.375
4	43.5	28.5	15	0.033956	2331.15	25	21	1.190476	1.4375
5	44	28	16	0.042445	2486.56	26	21	1.238095	1.46875
6	44	28	16	0.050934	2486.56	27	21.5	1.255814	1.515625
7	44.5	27.5	17	0.059423	2641.97	29	22	1.318182	1.59375
8	45	27	18	0.067912	2797.38	31	22	1.409091	1.65625
9	45	27	18	0.076401	2797.38	33	22.5	1.466667	1.734375
10	45.5	26.5	19	0.08489	2952.79	36	23	1.565217	1.84375
9	45	27	18	0.076401	2797.38	31	22	1.409091	1.65625
8	44.5	27.5	17	0.067912	2641.97	30	22	1.363636	1.625
7	44	28	16	0.059423	2486.56	28	21	1.333333	1.53125
6	44	28	16	0.050934	2486.56	27	21	1.285714	1.5
5	44	28	16	0.042445	2486.56	25	21	1.190476	1.4375
4	43.5	28.5	15	0.033956	2331.15	24	21	1.142857	1.40625
3	43	29	14	0.025467	2175.74	23	20	1.15	1.34375
2	43	29	14	0.016978	2175.74	22	20	1.1	1.3125
1	42.5	29.5	13	0.008489	2020.33	17	17	1	1.0625
0	36	36	0	0	0	16	16	1	1

At Hs-18cm,121.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	18	18	1	1
1	44	28	16	0.008489	2486.56	22	22	1	1.222222
2	44.5	27.5	17	0.016978	2641.97	27.5	24	1.145833	1.430556
3	44.5	27.5	17	0.025467	2641.97	29	24	1.208333	1.472222
4	45	27	18	0.033956	2797.38	31	24	1.291667	1.527778
5	45	27	18	0.042445	2797.38	32	25	1.28	1.583333
6	45.5	26.5	19	0.050934	2952.79	32	25	1.28	1.583333
7	45.5	26.5	19	0.059423	2952.79	33	26	1.269231	1.638889
8	46	26	20	0.067912	3108.2	36	26	1.384615	1.722222
9	46	26	20	0.076401	3108.2	39	26	1.5	1.805556
10	47	25	22	0.08489	3419.02	41	27	1.518519	1.888889
9	46	26	20	0.076401	3108.2	36	27	1.333333	1.75
8	45.5	26.5	19	0.067912	2952.79	35	26	1.346154	1.694444
7	45.5	26.5	19	0.059423	2952.79	33	26	1.269231	1.638889
6	45	27	18	0.050934	2797.38	32	25	1.28	1.583333
5	44.5	27	17.5	0.042445	2719.675	31	25	1.24	1.555556
4	44.5	27.5	17	0.033956	2641.97	30	24	1.25	1.5
3	44	27.5	16.5	0.025467	2564.265	29	24	1.208333	1.472222
2	44	28	16	0.016978	2486.56	27	24	1.125	1.416667
1	44	28	16	0.008489	2486.56	21	21	1	1.166667
0	36	36	0	0	0	18	18	1	1

At Hs-21cm,12.2rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	21	21	1	1
1	45	27.5	17.5	0.008489	2719.675	24	24	1	1.142857
2	45	27	18	0.016978	2797.38	31	26	1.192308	1.357143
3	45.5	26.8	18.7	0.025467	2906.167	32	26	1.230769	1.380952
4	45.5	26.5	19	0.033956	2952.79	32	26	1.230769	1.380952
5	46	26	20	0.042445	3108.2	33	27	1.222222	1.428571
6	46	26	20	0.050934	3108.2	34	27	1.259259	1.452381
7	46.5	26	20.5	0.059423	3185.905	36	28	1.285714	1.52381
8	46.5	25.5	21	0.067912	3263.61	41	28	1.464286	1.642857
9	47	25	22	0.076401	3419.02	41	29	1.413793	1.666667
10	47.5	24.5	23	0.08489	3574.43	42	30	1.4	1.714286
9	46.5	25	21.5	0.076401	3341.315	39	29	1.344828	1.619048
8	46.5	25	21.5	0.067912	3341.315	38	28	1.357143	1.571429
7	46.5	25.5	21	0.059423	3263.61	37	28	1.321429	1.547619
6	46	26	20	0.050934	3108.2	35	27	1.296296	1.47619
5	46	26	20	0.042445	3108.2	33	27	1.222222	1.428571
4	45.5	26.5	19	0.033956	2952.79	33	26.5	1.245283	1.416667
3	45	27	18	0.025467	2797.38	30	26	1.153846	1.333333
2	45	27.5	17.5	0.016978	2719.675	30	26	1.153846	1.333333
1	44	28	16	0.008489	2486.56	22	22	1	1.047619
0	36	36	0	0	0	21	21	1	1

Material-Silicon Carbide (dp-70µm)

At 73.9rpm,Hs-16cm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	43.5	28	15.5	0.008489	2408.855	17	17	1	1.0625
2	47.5	24	23.5	0.016978	3652.135	20	20	1	1.25
3	48	23	25	0.025467	3885.251	23	21	1.095238	1.375
4	48.5	22.5	26	0.033956	4040.661	27	21.5	1.255814	1.515625
5	49	22	27	0.042445	4196.071	29	22	1.318182	1.59375
6	49	22	27	0.050934	4196.071	30	22.5	1.333333	1.640625
7	49.5	21.5	28	0.059423	4351.481	32	22.5	1.422222	1.703125
8	50	21	29	0.067912	4506.891	34	23	1.478261	1.78125
9	51	20.5	30.5	0.076401	4740.006	36	24	1.5	1.875
10	52	20	32	0.08489	4973.121	39	25	1.56	2
9	50	21	29	0.076401	4506.891	35	24	1.458333	1.84375
8	49.5	21.5	28	0.067912	4351.481	32	23	1.391304	1.71875
7	49	22	27	0.059423	4196.071	31	23	1.347826	1.6875
6	49	22	27	0.050934	4196.071	31	22.5	1.377778	1.671875
5	48.5	23	25.5	0.042445	3962.956	29	22	1.318182	1.59375
4	48.5	23	25.5	0.033956	3962.956	25	21	1.190476	1.4375
3	47.5	24	23.5	0.025467	3652.135	23	21	1.095238	1.375
2	47.5	24	23.5	0.016978	3652.135	21	20	1.05	1.28125
1	41.5	30	11.5	0.008489	1787.215	18	18	1	1.125

At 101.6 rpm, Hs-16cm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	42.5	29	13.5	0.008489	2098.035	16.5	16.5	1	1.03125
2	47	24	23	0.016978	3574.43	20	19	1.052632	1.21875
3	48	23.5	24.5	0.025467	3807.545	22	20	1.1	1.3125
4	48.5	23	25.5	0.033956	3962.956	24	21	1.142857	1.40625
5	49	22.5	26.5	0.042445	4118.366	26	21.5	1.209302	1.484375
6	49.5	22	27.5	0.050934	4273.776	29	22	1.318182	1.59375
7	50	22	28	0.059423	4351.481	30	22.5	1.333333	1.640625
8	50.5	21	29.5	0.067912	4584.596	31	23	1.347826	1.6875
9	50.5	21	29.5	0.076401	4584.596	32	23	1.391304	1.71875
10	53	19	34	0.08489	5283.941	37	25	1.48	1.9375
9	50	21.5	28.5	0.076401	4429.186	32	23	1.391304	1.71875
8	49.5	22	27.5	0.067912	4273.776	31	23	1.347826	1.6875
7	49	22	27	0.059423	4196.071	29	22	1.318182	1.59375
6	49	22	27	0.050934	4196.071	28	22	1.272727	1.5625
5	48	23	25	0.042445	3885.251	25	21	1.190476	1.4375
4	48	23	25	0.033956	3885.251	23	21	1.095238	1.375
3	47.5	24	23.5	0.025467	3652.135	22	20.5	1.073171	1.328125
2	47.5	29	18.5	0.016978	2875.085	19	19	1	1.1875
1	42	29.5	12.5	0.008489	1942.625	17.5	17.5	1	1.09375
0	36	36	0	0	0	16	16	1	1

At-121.2rpm,Hs-16cm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	43	29	14	0.008489	2175.74	17	17	1	1.0625
2	47.5	23.5	24	0.016978	3729.84	21	20	1.05	1.28125
3	48	23.5	24.5	0.025467	3807.545	22	20	1.1	1.3125
4	48.5	23	25.5	0.033956	3962.956	24	21	1.142857	1.40625
5	49	22.5	26.5	0.042445	4118.366	25	21	1.190476	1.4375
6	50	22	28	0.050934	4351.481	29	22	1.318182	1.59375
7	50	22	28	0.059423	4351.481	30	22	1.363636	1.625
8	50.5	21.5	29	0.067912	4506.891	30	23	1.304348	1.65625
9	51	21	30	0.076401	4662.301	31	23	1.347826	1.6875
10	52	20	32	0.08489	4973.121	36	24	1.5	1.875
9	50	21	29	0.076401	4506.891	31	23	1.347826	1.6875
8	49.5	21.5	28	0.067912	4351.481	30	22	1.363636	1.625
7	49	22	27	0.059423	4196.071	29	22	1.318182	1.59375
6	49	22	27	0.050934	4196.071	27	22	1.227273	1.53125
5	48.5	23	25.5	0.042445	3962.956	24	21	1.142857	1.40625
4	48	23.5	24.5	0.033956	3807.545	23	21	1.095238	1.375
3	48	23.5	24.5	0.025467	3807.545	22	21	1.047619	1.34375
2	47	24.5	22.5	0.016978	3496.725	19	19	1	1.1875
1	41	30	11	0.008489	1709.51	17.5	17.5	1	1.09375
0	36	36	0	0	0	16	16	1	1

At 137.4 rpm,Hs-16cm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	36	36	0	0	0	16	16	1	1
1	43	29	14	0.008489	2175.74	17	17	1	1.0625
2	47.5	24	23.5	0.016978	3652.135	19	19	1	1.1875
3	48	23.5	24.5	0.025467	3807.545	21	20	1.05	1.28125
4	48.5	23	25.5	0.033956	3962.956	23	21	1.095238	1.375
5	49	23	26	0.042445	4040.661	24	21	1.142857	1.40625
6	49.5	22	27.5	0.050934	4273.776	27	21.5	1.255814	1.515625
7	49.5	22	27.5	0.059423	4273.776	29	22	1.318182	1.59375
8	50.5	21	29.5	0.067912	4584.596	31	22	1.409091	1.65625
9	51	21	30	0.076401	4662.301	31	23	1.347826	1.6875
10	52	20	32	0.08489	4973.121	32	23.5	1.361702	1.734375
9	50	21	29	0.076401	4506.891	31	23	1.347826	1.6875
8	50	21.5	28.5	0.067912	4429.186	29	22.5	1.288889	1.609375
7	49.5	22	27.5	0.059423	4273.776	29	22	1.318182	1.59375
6	49	22	27	0.050934	4196.071	27	22	1.227273	1.53125
5	48	23	25	0.042445	3885.251	25	21	1.190476	1.4375
4	48	23	25	0.033956	3885.251	24	21	1.142857	1.40625
3	47	24	23	0.025467	3574.43	22	20	1.1	1.3125
2	46	25	21	0.016978	3263.61	20	19	1.052632	1.21875
1	42	29.5	12.5	0.008489	1942.625	17	17	1	1.0625
0	36	36	0	0	0	16	16	1	1

Material-Magnetite (dp-60µm)

At 73.9 rpm,Hs-16cm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	35	35.5	0	0	0	16	16	1	1
1	44.5	26.5	18.5	0.008489	2875.085	20	19	1.052632	1.21875
2	45	25	20.5	0.016978	3185.905	23	21	1.095238	1.375
3	45	25	20.5	0.025467	3185.905	24	21.5	1.116279	1.421875
4	45.5	24.5	21.5	0.033956	3341.315	25	22	1.136364	1.46875
5	46	24	22.5	0.042445	3496.725	27.5	22	1.25	1.546875
6	46	24	22.5	0.050934	3496.725	29	22.5	1.288889	1.609375
7	47	23	24.5	0.059423	3807.545	32	23	1.391304	1.71875
8	47	23	24.5	0.067912	3807.545	34	23	1.478261	1.78125
9	47	23	24.5	0.076401	3807.545	37	24	1.541667	1.90625
10	47.5	22.5	25.5	0.08489	3962.956	41	24	1.708333	2.03125
9	47	23	24.5	0.076401	3807.545	38	24	1.583333	1.9375
8	47	23	24.5	0.067912	3807.545	36	23	1.565217	1.84375
7	47	23	24.5	0.059423	3807.545	35	23	1.521739	1.8125
6	46.5	23.5	23.5	0.050934	3652.135	33	22.5	1.466667	1.734375
5	46	24	22.5	0.042445	3496.725	29	22	1.318182	1.59375
4	45	25	20.5	0.033956	3185.905	28	21	1.333333	1.53125
3	45	25	20.5	0.025467	3185.905	25	20	1.25	1.40625
2	45	25	20.5	0.016978	3185.905	23	18	1.277778	1.28125
1	44	26	18.5	0.008489	2875.085	20	19	1.052632	1.21875
0	35	35.5	0	0	0	16	16	1	1

At 101.6rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	35	35.5	0	0	0	16	16	1	1
1	45	26	19.5	0.008489	3030.495	20.5	19.5	1.051282	1.25
2	45	25	20.5	0.016978	3185.905	22	20	1.1	1.3125
3	46	24.5	22	0.025467	3419.02	24	20	1.2	1.375
4	46	24	22.5	0.033956	3496.725	26	20	1.3	1.4375
5	46	24	22.5	0.042445	3496.725	28	21	1.333333	1.53125
6	48	22	26.5	0.050934	4118.366	31	23	1.347826	1.6875
7	48	21.5	27	0.059423	4196.071	33	23	1.434783	1.75
8	48	21	27.5	0.067912	4273.776	36	23	1.565217	1.84375
9	48	21	27.5	0.076401	4273.776	39	24	1.625	1.96875
10	48	20.5	28	0.08489	4351.481	42	25	1.68	2.09375
9	48	21	27.5	0.076401	4273.776	40	24	1.666667	2
8	48	21.5	27	0.067912	4196.071	38	24	1.583333	1.9375
7	47	22	25.5	0.059423	3962.956	36	23	1.565217	1.84375
6	47	22	25.5	0.050934	3962.956	33	22	1.5	1.71875
5	47	22	25.5	0.042445	3962.956	31	21	1.47619	1.625
4	46	23	23.5	0.033956	3652.135	27	20	1.35	1.46875
3	45	24	21.5	0.025467	3341.315	24	19	1.263158	1.34375
2	44	25	19.5	0.016978	3030.495	22	19	1.157895	1.28125
1	43	26	17.5	0.008489	2719.675	21	19	1.105263	1.25
0	35	35.5	0	0	0	16	16	1	1

At 121.2 rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	35	35.5	0	0	0	16	16	1	1
1	44.5	25	20	0.008489	3108.2	21	20	1.05	1.28125
2	46	24	22.5	0.016978	3496.725	23	20	1.15	1.34375
3	46	24	22.5	0.025467	3496.725	26	20	1.3	1.4375
4	47	23	24.5	0.033956	3807.545	29	21	1.380952	1.5625
5	47	23	24.5	0.042445	3807.545	31	22	1.409091	1.65625
6	47	23	24.5	0.050934	3807.545	32	24	1.333333	1.75
7	47	23	24.5	0.059423	3807.545	33	24	1.375	1.78125
8	47.5	22	26	0.067912	4040.661	35	24	1.458333	1.84375
9	48	21	27.5	0.076401	4273.776	37	24	1.541667	1.90625
10	48	21	27.5	0.08489	4273.776	39	25	1.56	2
9	48	21	27.5	0.076401	4273.776	38	25	1.52	1.96875
8	47	22	25.5	0.067912	3962.956	36	24	1.5	1.875
7	47	22	25.5	0.059423	3962.956	34	24	1.416667	1.8125
6	47	22.5	25	0.050934	3885.251	33	23	1.434783	1.75
5	46	23	23.5	0.042445	3652.135	31	22	1.409091	1.65625
4	46	23	23.5	0.033956	3652.135	29	22	1.318182	1.59375
3	45	24	21.5	0.025467	3341.315	26	21	1.238095	1.46875
2	44	25	19.5	0.016978	3030.495	23	20	1.15	1.34375
1	44	25	19.5	0.008489	3030.495	21	19	1.105263	1.25

At 137.4 rpm

Flow Rate(lpm	h1(cm)	h2(cm)	(h1-h2)	Usup(m/sec)	del P	Hmax(cm)	Hmin(cm)	r	R
0	35	35.5	0	0	0	16	16	1	1
1	43	24	19.5	0.008489	3030.495	21	20	1.05	1.28125
2	44	23	21.5	0.016978	3341.315	23	21	1.095238	1.375
3	44	23	21.5	0.025467	3341.315	25	22	1.136364	1.46875
4	44	23	21.5	0.033956	3341.315	26	23	1.130435	1.53125
5	45	22	23.5	0.042445	3652.135	28	223	0.125561	7.84375
6	45	22	23.5	0.050934	3652.135	30	24	1.25	1.6875
7	45	22	23.5	0.059423	3652.135	31	25	1.24	1.75
8	46	21	25.5	0.067912	3962.956	33	25	1.32	1.8125
9	46	21	25.5	0.076401	3962.956	35	26	1.346154	1.90625
10	46	21	25.5	0.08489	3962.956	37	26	1.423077	1.96875
9	46	21	25.5	0.076401	3962.956	36	26	1.384615	1.9375
8	45.5	22	24	0.067912	3729.84	34	25	1.36	1.84375
7	45	23	22.5	0.059423	3496.725	33	25	1.32	1.8125
6	45	23	22.5	0.050934	3496.725	31	24	1.291667	1.71875
5	44	24	20.5	0.042445	3185.905	30	24	1.25	1.6875
4	44	24	20.5	0.033956	3185.905	29	23	1.26087	1.625
3	43	25	18.5	0.025467	2875.085	27	22	1.227273	1.53125
2	43	25	18.5	0.016978	2875.085	24	21	1.142857	1.40625
1	43	25	18.5	0.008489	2875.085	22	21	1.047619	1.34375
0	35	35.5	0	0	0	16	16	1	1